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An Evaluation of Habitat Structure and the Distribution of Rare and Common Darters in Ohio

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AN EVALUATION OF HABITAT STRUCTURE AND THE DISTRIBUTION OF RARE AND COMMON DARTERS IN OHIO

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By

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Abstract

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Darters are small benthic-feeding fish. I examined reasons why some darter species are rarer than others based on geographic range, habitat specificity, and local population size using the Ohio EPA database and field research. The Qualitative Habitat Evaluation Index (QHEI) represented habitat quality. I examined drainage area and gradient at the landscape-scale, riparian and channel characteristics at the reach-scale, and substrate, cover, and riffle/pool characteristics at the microhabitat scale. Some rare species occur in few rivers in Ohio, but throughout a basin, while other rare species occur only in moderate-sized rivers. Most rare species occur at only a few sites with low abundance. Common darters occurred in all-sized rivers and gradients. Rare darters occurred in large drainage areas with moderate gradients. Species richness was positively correlated with high QHEI, although the common johnny darter was abundant at sites with low QHEI. Mesohabitat and microhabitat were examined for each darter species within the species-rich Scioto River and Muskingum River basins. Rare species were more associated with high quality habitat than common species. Within Battelle-Darby Creek Metropark, a site with good habitat quality, species distributions differed. Overall, watershed size was the best predictor for a darter’s distribution.

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INTRODUCTION

A watershed is the land that water flows across or under to reach a river or lake. Rivers themselves are composed of different hydrologic units-pools, runs, and riffles-, which often support different assemblages of aquatic organisms. Early in the 20th century, Ohio ichthyologist Milton B. Trautman monitored Ohio stream fishes extensively, recording fish distributions and their broad habitat requirements (Trautman, 1957). Currently, the Ohio Environmental Protection Agency (Ohio EPA, 2010) monitors fish abundances and records habitat characteristics throughout the state. Ohio is a critical part of the range of the North American darter assemblages. Darters are small, brightly-colored, benthic-feeding fishes of the genera *Etheostoma, Percina*, or the lesser-known *Ammocrypta* (Trautman, 1957; Page, 1983; Kuehne & Barbour, 1983). Darters are found in the Mississippi River system and drainages of the Great Lakes, Hudson Bay, Atlantic Coast, Gulf of Mexico, and Pacific Coast of Mexico (Page, 1983). There are nineteen species of darters in Ohio (Table 1), and fourteen of those species occur in central Ohio's Big Darby Creek—a tributary of the Scioto River basin. My study utilized the Ohio EPA fish database to further examine darter habitats and darter distributions at various spatial scales. I also studied a highly diverse watershed in Ohio—Big Darby Creek—and the presence/absence of darters in its riffles. This study focused on the distributions of common and rare darters in Ohio and the influence of physical habitat characteristics on their distribution. The examination of darter distributions allows for a better understanding of darter ecology and the habitat requirements needed in order to develop a framework that addresses conservation targets at multiple scales.

I defined each darter species as common or rare based on Rabinowitz's seven forms of rarity (1981). According to Rabinowitz, there are eight types of species diversity patterns: one common and seven rare. She defines common species as having large local population size and dominance, wide habitat-specificity, and large geographic range. Species are considered rare based on habitat specificity, local population size, and geographic range. In this study, I define a population as the density of individuals within an area. Species with restricted distributions can be locally abundant over a range in a specific habitat, constantly sparse in a specific habitat but restricted geographically, locally abundant in a specific habitat but restricted geographically, or constantly sparse and geographically restricted in a specific area (Rabinowitz, 1981). I divided species in this study into two groups: rare or common based on these patterns and described the distribution pattern observed for each darter species. In general, common species have widespread geographic ranges with high densities of individuals and a broad habitat tolerance. In contrast, rare species have restricted geographic ranges and relatively low densities.

Rare darters in Ohio probably have always had extremely limited ranges and low numbers of individuals within their ranges (Page, 1983). Their restricted distributions may reflect narrow habitat requirements. By knowing rare darters' distributions and habitat preferences, I can determine habitat types that should be conservation targets, especially if these species are sensitive to environmental changes.

Darters of the genus *Etheostoma* primarily inhabit riffles, which are usually characterized by structural complexity (Page, 1983). In contrast, darters of the genus *Percina* are found in runs and pools. The examination of habitat use by darters use can help in understanding how well darters can tolerate their environment (Table 2). For instance, different species within the genera *Percina* and *Etheostoma* prefer areas within a habitat unit that have varying flow regimes or substrate bottoms and move in between habitats seasonally based on temperature and water velocity. Their distributions may also change as a result of increased turbidity or pollutants into their habitat (Page, 1983).

Darters use the physical structure on the stream bottom to avoid predators, as a refuge from current, and for egg attachment during spawning season (Page, 1983; Harding et al., 1998). Different sized substrates allow for various refuge and attachment of eggs. The Ohio EPA categorizes sand as materials between 0.06-2.0mm in diameter with a gritty texture when rubbed between fingers (State of Ohio, 2006) and is poor living or spawning substrate for most darters since it does not provide cover. Gravel is a mixture of rounded coarse material from 2-64mm in diameter and provides suitable attachment or burial for darter eggs during spawning (State of Ohio, 2006; Page 1983).

Although species of the genus *Etheostoma* are found predominantly in riffles, they are not strong swimmers and need refuge from high velocities, especially during periods of intense flow. Large substrates, such as cobble and boulder, within riffles provide a critical function to darters by protecting them from strong flows. The Ohio EPA categorizes cobble as stones from 64-256mm in diameter, while boulders are rounded stones over 256mm in diameter or large slabs more than 256mm in length (State of Ohio, 2006). Large substrates create eddies or microhabitat shelters with low water velocities that darters use as refuge (Schlosser & Toth, 1984; Chipps et al., 1994; Harding et al. 1998). Substrate size and shape, water velocity, and discharge interact to produce microhabitat shelters at various locations within the stream bed (Schlosser & Toth, 1984).

Water temperature varies across both space and time. Vegetation along the stream bank shades the river during the dry season moderating the stream temperature over the day. The removal of riparian vegetation raises the temperature of stream water, often beyond the tolerance of species. Darters often have to make local movements into different habitats rather than remaining in their preferred habitat. Spawning usually occurs in early to late spring in riffles (Trautman, 1957; Page, 1983). It begins with a pre-spawning shift into the spawning habitat (i.e., riffle) during early spring. After spawning, adults remain in fairly shallow riffles during the summer. Most species overwinter in low-gradient, deeper habitats such as pools (Page, 1983). Some species of darters, such as the banded and greenside do not have seasonal movements (Wynes & Wissing, 1982). In contrast, bluebreast darters may move long distances from upstream to downstream reaches during spawning, or to escape fluctuations in temperature and flow (Trautman, 1957). Persistence of rare darters may depend on large areas of contiguous stream habitat that offer these refuges from environmental fluxes.

Evaluation of landscape-scale elements on darter distributions: Ohio EPA's Qualitative Habitat Evaluation Index (QHEI)

Researchers have examined the distribution of darters at the watershed level, reach-level, and within contiguous habitat units (Chipps & Perry, 1994; Harding et al., 1998; Mattingly & Galat, 2002; Walters et al., 2003). Rivers can be functionally divided into different structural components. A reach is a segment of the river that includes several types of macro-habitats including pools, runs, and riffles. A pool is a deep, slow flowing habitat where fine sediments accumulate. Pools have a positive gradient or elevation at the downstream end. In contrast, a riffle is a downward sloping stretch characterized by shallow depths, high velocities, and relatively large substrates. A run is an intermediate habitat type characterized by moderate depths, low gradient, and laminar flow (State of Ohio, 2006). These varied habitats are necessary to maintain a diverse assemblage of darters. My study examines factors that may influence the distributions of common and rare darters at the landscape-scale, reach-scale, and habitat scale through the use of the EPA's Qualitative Habitat Evaluation Index (QHEI).

Since the 1970's, the Ohio Environmental Protection Agency has recorded darter locations and habitat characteristics of stream sites throughout Ohio during the months of June-August (Rankin, 1995). The EPA database has several thousand records of habitat descriptions and the fish species that are found at particular sites. I subset the fish records from the Ohio EPA to restrict my analysis to sites where darters were sampled. The Ohio EPA uses a QHEI score to evaluate each site. Each site is approximately 200 meters in length and includes a riffle-run-pool sequence. The QHEI includes a substrate score, cover score, channel score, riparian score, pool/run/riffle score, and gradient score that combines gradient and drainage area (refer to methods for a detailed description of the scores). Combined, these scores reflect the status of a habitat. High numbers represent pristine habitat and low numbers poor quality habitat. Although the Ohio EPA considers the QHEI as a macro-scale approach that measures emergent properties of habitat (Rankin, 1989), I broke down the components of the QHEI score into landscape-, reach-, and micro-habitat scales.

<u>Evaluation of habitat use by darters on a smaller scale: within a segment of a basin</u>

The QHEI gives habitat information on a large scale, and the EPA uses this information to establish conservation priorities. One stream of importance in Ohio is Big

Darby Creek, which has relatively pristine waters and a high species richness of fish and mussel species. The Ohio EPA and Ohio Department of Natural Resources have made protection of Big Darby Creek and its fauna a high conservation priority. I studied a segment of this creek at a finer scale to assess rare darter distribution and habitat quality in a well protected, mid-order stream. Tippecanoe darters, bluebreast darters, and spotted darters are considered rare species that occur in Big Darby Creek, and understanding the habitat requirements that affect rare darter distributions will help in the creation of future management plans.

Objectives

I examined rare and common darter distributions and habitat use at three geographic scales: 1) state of Ohio, 2) two watersheds, and 3) a portion of Big Darby Creek watershed. There were two main objectives in this study: 1) to determine how common and rare darters segregate based on reach-scale habitat and microhabitat variables defined by the Ohio EPA and 2) to describe the distribution of darters within the portion of the Big Darby Creek that has been a long-term target of stream conservation.

Hypothesis 1: Drainage area and gradient are physical attributes that affect stream size and flow. Each darter species will have a range of stream sizes where it occurs.

Hypothesis 2: If the QHEI is to be useful, then there will be a positive relationship between habitat quality (QHEI) and darter abundance.

Hypothesis 3: Different species of darters will have specific habitat needs for small-scale, microhabitat components of substrate, cover, pool, and riffle quality.

METHODS

Large-scale habitat influence on darter distributions

There are currently nineteen darters species in Ohio. I used historical maps from Page and ArcGIS maps of darter sites taken from the Ohio EPA fish database to represent the distributions of darters in Ohio while larger-scale maps show the entire distribution of each darter species. The distributions of darters in Ohio reflect the sites sampled by the Ohio EPA since the 1970's. In order to explore types of rarity seen with Ohio darters, I averaged fish densities at a given site over all years that the site was sampled. I compared the number of sites at which a given species occurred with the average number of individuals of a given species per site. Sites at which the species were present were included in this average. This treatment will tend to inflate the average density of a species within its range, but gives a more informative average than including zeros from sites outside the species range or zeros representing unsuitable habitat within the species range. I compared the average density of each darter species in Ohio to the number of sites with that particular species. I also correlated the total number of individuals of each species within Ohio to the number of sites with that species.

I used darter records and corresponding site characteristics from the Ohio EPA fish database to analyze the relationship between habitat characteristics and darter distributions at multiple spatial scales. I assessed the relationship between habitat quality and the abundance of darters. Habitat variables were not available for every fish collection date, but I treated each river mile as a unique site and only included sites in the analysis for which habitat data was available. A river mile is recorded by the Ohio EPA out to the tenths place of a mile. I combined darter abundance data and habitat information using SAS 9.0. I averaged the number of darters recorded over a given year and then averaged within sites among years. I matched darter data with habitat data according to basin code, stream code, river name, river mile. A site was only represented once.

The Ohio EPA uses a QHEI score to evaluate stream habitat quality (Rankin, 1995). Habitat characteristics consisted of numeric scores for cover, channel, riparian, substrate, pool quality, and riffle quality and of continuous variables for gradient (ft/mi) and drainage area (mi^2) (Table 2). In order to assess darter distribution in Ohio with respect to large-scale habitat elements, I analyzed the correlation between darter abundance and gradient and drainage area for the entire state of Ohio. I compared the total distribution of each darter species with respect to gradient and drainage area and then looked at specific watersheds. I log transformed gradient (ft/mi) and drainage area (mi^2) data of each site. I correlated the number of darter species present at a site against QHEI and a reported a correlation. I plotted the number of darter individuals for two common darters, the greenside and johnny darters, against the QHEI at sites where they were found and performed a correlation. I further analyzed darter macro- and microhabitat within two Ohio drainage basins with the highest number of darter species.

<u>Intermediate-scale habitat influence on darter distributions: Scioto and Muskingum River Basins</u>

I chose two large basins in Ohio with the greatest number of darter species: the Scioto River basin and Muskingum and Little Hocking River Basin. (The Muskingum and Little Hocking River Basin will be referred to as the Muskingum River Basin throughout the remainder of this study). The Scioto River Basin is located in central to southern Ohio (Figure 5). The Muskingum River Basin is located in southeastern Ohio (Figure 5). Mesoscale habitat was analyzed for both common darters and rare darters by comparing presence versus absence at sites with darters. Reach-scale components included QHEI sub scores for channel and riparian quality. The channel score quantifies channel sinuosity, the development or good definition of riffle/pool complexes, down-cutting, and stability. The Ohio EPA assigns a high channel score to regions that have high sinuosity with well-defined riffles present with large substrates and varying pool depths. A high channel score would be given to streams that are recovering from being channelized in the past and that have stable banks with little or no erosion present. Riparian score emphasizes the quality of the riparian buffer zone and quality of floodplain vegetation. This score includes riparian zone width, floodplain quality, and extent of bank erosion. A high score indicates a wide riparian area (>50m) surrounded by forest or swamp with little to no bank erosion (State of Ohio, 2006).

For each basin, I compared the reach-scale habitat score difference between sites where a darter species occurred versus sites where that species did not occur. I weighted site scores based on the number of individuals present for each darter species. I also made this comparison for the total QHEI score and microhabitat scores. In SAS, I used a Kolmogorov-Smirnov test to show how each element of the QHEI impacts a species' abundance. I used the resulting D-statistic and p-values ($p<0.01$ and $p<0.05$) to show the greatest discrepancy between the observed and expected cumulative frequencies for each QHEI element for the sites with a darter species and the habitat where a specific darter is found. I plotted darter abundance (log transformed) against the D-statistic for QHEI and its components.

Microhabitat-scale influence on darter distributions

The Scioto River Basin and the Muskingum River Basin have high darter diversity relative to other watersheds in Ohio. This allowed me to compare the habitat requirements of rare and common species in 2 watersheds where both classes of darter occur. I assessed microhabitat quality using QHEI indices of riffle, pool, cover, and substrate quality. The substrate score includes the substrate type and substrate quality. A high substrate score indicates availability of larger substrate types (i.e., boulder, slabs, cobble, and gravel) and diversity of substrate (i.e., presence of4 or more substrate types). The cover score evaluates the presence and overall amount of instream cover types (i.e., deep pools, root-wads, logs, aquatic plants). A high cover score indicates extensive cover or cover present throughout the sampling area (>75% stream area) (State of Ohio, 2006).

The pool/current score evaluates the quality of pool habitats. A high pool score indicates a maximum depth >1m with pool widths greater than the width of nearby fast riffle habitats. The riffle/run score quantifies the quality of riffles and runs, which ideally are relatively deep with coarse substrates. A high riffle/run score indicates a riffle depth >10cm and run depth >50cm with stable substrates and no accumulated sand (State of Ohio, 2006).

For each basin, I compared the microhabitat score difference between sites where a darter occurred versus sites where that species did not occur. I weighted site scores based on the number of individuals present for each darter species. In SAS, I used a Kolmogorov-Smirnov test to show how each element of the QHEI impact a darter's abundance. I used the resulting D-statistic and p-values ($p>0.01$ and $p>0.05$) to show the greatest discrepancy between the observed and expected cumulative frequencies for each microhabitat QHEI element for sites where a darter is present and the habitat where a darter is absent. The D-statistic for each species was then compared to darter abundance (log transformed).

A microhabitat field study: Big Darby Creek's riffle-dwelling darters

Understanding the impacts of humans on fish distributions is essential for conserving aquatic communities. Some of the best darter habitat in Big Darby Creek occurs within the Battelle-Darby Creek Metro Park. This section has a well preserved riparian buffer zone and a heterogeneous streambed. Of the fourteen species of darters in Big Darby Creek, one is endangered (spotted darter) and two are threatened (tippecanoe darter and bluebreast darter) (ODNR, 2010). Big Darby Creek watershed is located in central Ohio and drains a large agricultural watershed (1,443 km^2) and is intensely monitored by the Ohio EPA (Cormier et al., 2000). The stream has relatively high water quality, high aquatic diversity, and a narrow, but intact, riparian zone (Cormier et al., 2000). Within the watershed, there has been an increase in the removal of riparian vegetation upstream of the metro park for agriculture and urban developments. Agriculture causes an excess of nutrients and sediments, while urbanization causes an increase in nutrients and storm water contaminants in the stream. Therefore, increasing urbanization in the upstream reaches has the potential to alter darter habitat within the metro park area. Understanding the impacts of humans on fish distributions is essential for conserving aquatic communities.

I conducted a field study in Big Darby Creek, a stream within the Kokosing River basin. This study took place during the post-spawning season June-October 2005 and May-August 2006. I surveyed a thirteen-kilometer stretch of Big Darby Creek bordered by riparian buffers within the Battelle-Darby Creek Metro Park. During June and July 2005, I characterized habitat units along Big Darby Creek either as pools, riffles, or runs based on stream characteristics by visually examining the water velocity, depth, and stream bottom substrates. The coordinates were taken using a GPS ETREX Legend (±5m) (Coordinate system: WGS 1984). According to site characteristics, there were thirty-two riffles along the stretch of Big Darby Creek within the metro park. Site 1 was the most upstream site and sites were numbered sequentially in a down-stream progression.

During summer 2005, I sampled darters with a kick net (3.2mm mesh seine, 1.2m x 1.8m) at each of the thirty-two sites. Ten one-minute kick net samples were taken in each riffle. Kick net sampling involved vigorously disturbing the substrate directly upstream of the net (approximately a $1m^2$ area) to force fish into the net. I identified darters by species and counted them after placing them into a bucket or plastic container. The kick net sampling gave a qualitative assessment of the presence or absence of species. I created pie charts showing the abundance of common and rare darter species in 32 riffles of a 13km stretch of Big Darby Creek within Batelle-Darby Creek Metopark. The pie charts varied by size according the number of darters present.

I characterized the substrate of each riffle. I placed a $0.25m^2$ quadrat with twenty-five intersections at five areas within the riffle. Substrates at each grid intersection were categorized based on size: sand/gravel, cobble (small, medium, and large), and boulder. I averaged the proportion of each substrate type for all 32 sites. The percentage of a site's surface covered by a given substrate was plotted for the rare bluebreast, tippecanoe, and spotted darters and for the common darters, which included banded, logperch, rainbow, orangethroat, and johnny darters.

I placed temperature loggers (iButtons DS1922L-F) in fifteen riffles from April to October 2006. I chose the sites based on where rare darters occurred. I placed a logger in the middle of each riffle and set the logger to record temperatures every thirty minutes. At two sites, I placed loggers at the top, middle, and bottom to see if there were differences in temperature variation within riffles. I successfully retrieved only six (sites 3, 8, 12, 18, 26, and 30) out of nineteen loggers from the stream. All the recovered loggers were recovered in places from June 1 through July 31, 2006, so I only analyzed this time window. I calibrated the loggers under variable temperature ranges and calibrated against the most extreme iButton to correct for any differences among individual loggers. I regressed average daily temperatures against stream distance from June 1-July 31 2006 to see if it varied consistently with distance downstream. I also plotted daily discharges (cubic feet/second) from USGS from the end of May to the beginning of August 2006.

RESULTS

Forms of rarity: darter distributions in the Eastern United States and in Ohio

Banded, blackside, fantail, greenside, johnny, logperch, rainbow, and orangethroat darters, all common, are widespread across the Eastern United States with some ranges extending into Canada (Figure 1a-h). Ohio was at the center of the distribution of most of these darters but at the edge of the range for the banded and orangethroat darters (Figure 1e-f).

Dusky, least, slenderhead, variegate, bluebreast, channel, eastern sand, river, spotted, tippecanoe, and Iowa darters, all rare, occurred in fewer locations than the common darters. Some had a rather narrow geographical distribution and occurred in few locations (Figure 1i-s). The bluebreast, spotted, and tippecanoe darters (Figure 1l, r, and o) occurred in very few watersheds in the eastern United Sates and occur in two to three river basins in Ohio. The bluebreast darter had a narrow distribution, but was abundant (~7 individuals/site) where it occurred compared to other rare darters in Ohio (Figure 2a-b). Channel and river darters typically occurred in larger water bodies of the Ohio River and Lake Erie (Figure 1p-q). Compared to other rare darters, the Iowa darter had a fairly widespread distribution, occurring in both Canada and the Eastern United States, but Ohio is at the edge of its range (Figure 1s).

Based on these distributions, I identified four different types of abundance patterns (Figure 2a). Common darters included species with widespread distributions and high densities. Greenside, johnny, fantail, orangethroat, and banded darters are common darters that occur in Ohio. Another type of rarity in this study included some species that have widespread distributions (~2000 sites), but occurred in low densities (an average of

4-5 individuals/site). These species included the logperch and blackside darters. Variegate and least darters were rare darters that had narrow distributions, but had moderate densities where they were found. The variegate darter occurred at about three times as many sites as the least darter. Where present, the variegate darter had an average of 10 individuals per site present and the least darter had an average of 19 individuals per site. Compare this to the average of 4 individuals per species per site for all other rare darters. The rarest species had narrow distributions and low densities: bluebreast, river, tippecanoe, spotted, Iowa, eastern sand, channel, and slenderhead darters. The bluebreast darter was slightly more abundant where it occurs compared to other rare darters (Figure 2). About half of the darter species in Ohio were rare.

The common darters had a greater number of individuals present at a site and occurred in more locations than the rare darters. There was a positive linear relationship between the total number of individuals in Ohio and the number of sites where that species occurred ($p>0.05$, $R^2=0.9528$, $F=343$, $p<0.01$) (Figure 2b).

<u>Darter habitat at the landscape-scale</u>

Common darters occurred throughout the river basins in Ohio, and their distributions include headwater streams (Figures 3a and 4a). In contrast, rare darters occupied areas of the watershed that drain relatively large areas and have moderate gradients. However, the Iowa darter occurred only in small drainage areas. The majority of rare darter individuals were restricted to small geographic areas. For instance, 100% of Iowa darters collected by the survey occurred within a 3.2 square mile drainage area of the Cuyahoga River. The eastern sand darter occurred over a larger range of drainage areas compared to the other rare darters. Only river and channel darters were abundant in parts of the landscape with large drainage areas (Lake Erie and the Ohio River). The channel darter is also present in the Muskingum River.

Species richness was correlated with QHEI score ($p<0.05$, $R^2=0.1574$, $F=888$, $p<0.01$). Sites with less than 8 species encompassed a wide range of habitat quality (Figure 6). Sites with greater than 8 species had a better habitat and more species of rare darters (Figure 6). The greenside darter like most other common and rare darters had a positive relationship with habitat quality ($p<0.05$, $R^2=0.0348$, $F=123$, $p<0.01$) (Figure 7a), while johnny darter individuals are most abundant at sites with a low QHEI ($p<0.05$, $R^2=0.0451$, $F=129$, $p<0.01$) (Figure 7b).

<u>Distribution of darters within the Scioto and Muskingum basins</u>

The Scioto River Basin and the Muskingum River Basin are two large river basins in Ohio and have the greatest number of darter species (Table 3). The data from these basins allowed me to explore the relationship between darter presence and habitat quality.

Overall, Ohio had an average approximate QHEI score of 64 for all sites sampled from 1984 to 2004. The null expectation is that the Scioto and Muskingum River Basins will have similar QHEI scores. Sites in the Scioto River Basin (948 sites) had an average QHEI score of 68 (range 12-99). Sites in the Muskingum River Basin (750 sites) had an average QHEI score of 63 (range 16.5-97.5). The Scioto River Basin had eight common darters and nine rare darters while the Muskingum River Basin had eight common darters and eight rare darters. The same species of common darters were present in these basins, but different species of rare darters (Figure 8).

For both river basins and for most species, both common and rare, QHEI scores were higher where the species was present than where it was absent (Figure 8a-b). On average, rare darters occurred at better sites (higher QHEI scores) than common darters. Unlike other common darters, the johnny darter occurred at sites with consistently lower scores for all components of the QHEI. Some species differed in their habitat distributions between watersheds. For instance, the orangethroat darter had a lower QHEI at sites where they were present in the Scioto River Basin, but a higher QHEI at sites where they were present in the Muskingum River Basin.

The difference between QHEI scores where darters were present than where they were absent was consistently higher in the Muskingum River Basin than in the Scioto River Basin (Figure 8a-b). In the Scioto River Basin, the spotted darter had the greatest difference (approximately 20 points higher where present) in overall QHEI score whereas in the Muskingum River Basin the bluebreast darter had the greatest difference (approximately 23 points higher). In the Scioto River Basin, most rare darters were found at sites with QHEI scores significantly different (KS test result of $p>0.01$) from sites where they were absent (Figure 11a). Except for the blackside darter in the Scioto River Basin, common darters in both River Basins occurred at sites with overall QHEI scores significantly different ($p<0.01$) from sites where they were absent.

<u>Darter habitat at the reach-scale</u>

Mesoscale habitat elements (riparian and channel characteristics) appeared to have an impact on the distribution of some common and rare darter distributions (Figure 9, Figure 12). Channel score was better correlated with the distribution of darters for both basins than the other QHEI metrics (riparian characteristics and riparian vegetation). Several darters, both common and rare, had channel scores greater at sites where they were present than at sites where they were absent for both basins (Figure 9c-9d). The

Muskingum River Basin had greater channel score differences (approximately 4 points, sites where present minus sites where absent) than did the Scioto River Basin (approximately 2-3 points) for rare darters (Figure 9d). Although not significant (KS test result of $p>0.05$), the least darter had a lower channel score at sites where it was present than at sites where it was absent. This result suggests that sinuosity or any other component of channel score has little influence on the least darter's distribution (Figure 9d).

For overall difference in QHEI scores as well as mesoscale habitat of riparian and channel characteristics, darter abundance was correlated with the D-statistic (Figure 8, Figure 9, Table 4). Recall that the D-statistic represents the greatest discrepancy between the observed and expected relative cumulative frequencies between sites where the given species is present and the sites where it is absent. Rare darters had higher D-statistics compared to common darters. A higher D-statistic denotes that there was a greater difference in habitat quality at sites where the species was present than at sites where the species was absent. In comparison, common species, with high abundances, had lower D-statistics.

Microhabitat scale

For overall differences in microhabitat scores, darter abundance was correlated with the D-statistic (Figure 10, Table 4). Rare darters were associated with higher D-statistics than common darters. This D-statistic measured the absolute difference in relative cumulative frequency distributions between sites where the darter was present and sites where the species was absent.

The instream cover score, which evaluates the presence of instream cover types and amount of overall instream cover, was significant for most common and rare darter distributions. Sites in the Muskingum River Basin had greater cover score differences for the majority of common darters than the Scioto River Basin (Figure 10a, Figure 13b). These differences in scores were greater for rare darters in both river basins. Rare darters in the Muskingum River Basin had a greater cover score difference, positive or negative, at sites than the Scioto River Basin's darters (Figure 10b, Figure 13b). However, these differences were significant for only a select few rare darters in both basins, partly due to low sample sizes.

The majority of sites with common and rare darters in the Muskingum and Scioto River Basins had substrate scores significantly different from sites where they were absent (Figure 10c-10d, Figure 13c-13d). All sites with common and rare darters in the Muskingum River Basin had greater differences in substrate scores than sites where they were absent (Figure 10c-10d). Not all of these differences were significant (Figure 13c-13d). Sites with more common than rare darters in the Muskingum and Scioto River Basins had greater differences in substrate score than sites where they were absent (Figure 13c-13d). In the Muskingum River basin, tippecanoe and river darters occurred at sites that had approximately 10 more points than at sites where they were absent (Figure 13d). There was a problem of statistical power since rare darters only occurred at a few sites (Figure 13d).

The majority of sites with common and rare darters in the Scioto River Basin had pool scores significantly different from sites where they were absent (Figure 13e-13f). I also saw this significance for more common than rare species in the Muskingum River

Basin (Figure 13f). Rare darters occurred at sites with greater pool scores (approximately 2.5) in the Muskingum and Scioto River Basins than where they were absent (Figure 10e-10f).

Riffle scores were similar to substrate scores for individual species (Figure 10g-10h, Figure 10c-10d). The channel darter in the Muskingum River Basin was an exception to this. Sites where this species was present had a lower riffle score but a higher substrate score than sites where it was absent. Channel darters are associated with deeper waters (Trautman, 1957), so I expected this result. The majority of sites with common and rare darters in the Scioto and Muskingum River Basins had riffle scores significantly different (KS test result of $p<0.01$) from sites where they were absent (Figure 13g-13h).

A microhabitat analysis: Big Darby Creek

Average daily temperatures ranged from 17 to 27 ^{0}C between June 1, 2006-July 31, 2006 at six sites along Big Darby Creek (Figure 14). Downstream sites had higher temperatures than upstream sites. Average temperatures increased throughout the summer as expected. Temperatures were inversely related to the discharge for that time period.

I plotted darter densities at 32 sites along a 13km stretch of Big Darby Creek within the Battelle-Darby Creek Metro Park (Figure 15). Common darters included johnny, orangethroat, rainbow, logperch, greenside, and banded darters. These darters made up the majority of darters found at every site. Rare darters included bluebreast, spotted, and tippecanoe darters. The bluebreast darter occurred at 21 out of 32 sites; I captured more than one bluebreast darter at most sites. The spotted darter occurred at downstream sites while the tippecanoe darter occurred mainly within the mid-section of the stretch.

Large substrates of cobble and boulder made up the greatest average proportion of substrate type found at study sites (Figure 16a). Tippecanoe darters were present at sites where cobble occurred (Figure 16b-16d). Common, spotted, and bluebreast darters did not show a pattern with regard to substrate type (Figure 16b-16d).

DISCUSSION

Darters are the most endangered group of North American fishes, with roughly one-third of all darters having populations in decline (Boschung & Mayden, 2004). These small fish are vulnerable to stream degradation because they feed and reproduce in benthic habitats (Kuehne & Barbour, 1983; Ohio EPA, 1987). Various habitat scale variables, from landscape to microhabitat affected the distribution of darter species in my study. Watershed size was the best predictor for a darter's distribution; however other variables were also considered when it comes to conserving these species. For the majority of both common and rare darters, abundance was positively associated with elements of Ohio's QHEI.

The current distribution, as taken from the Ohio EPA database, of most common species, including johnny, rainbow, fantail, banded, blackside, and orangethroat darters has remained the same or has slightly increased in Ohio river basins compared to historic distributions recorded by Trautman (1957) and Page (1983). Some notable range expansions have occurred. The orangethroat darter currently occurs in the Muskingum River basin in addition to areas from its historical distribution in Ohio. The logperch darter currently is distributed at more sites along Lake Erie and in the Sandusky River compared to historic distributions. The distribution of greenside darter in the northwest quadrant of Ohio has contracted slightly since its historical distribution recorded by Trautman (1957).

Most rare darter species in Ohio have restricted distributions and low densities. Some rare species have always been rare in the state and are restricted to a few watersheds (Page, 1983). Extirpated darter species in Ohio include Crystal, longhead, and gilt darters (ODNR, 2010). The Iowa darter had a 1-2 individuals present at about 3 sites in Ohio back in 1986, but species are no longer being reported by the Ohio EPA. Ohio is at the edge of the least darters' distributions.

Eastern sand and least darters are listed as species of concern in Ohio (ODNR, 2010). Species in this category must be continually monitored either because of habitat degradation factors or other physical or biological characteristics that may cause them to become threatened or endangered (Boschung & Mayden, 2004). Least darters are relatively well distributed in the western part of Ohio in small sluggish prairie streams, natural lakes, and permanent wetlands that have clear water and an abundance of aquatic vegetation. Historically the least darter was perhaps more widely distributed where appropriate habitat was present (ODNR, 2010). The eastern sand darter used to occur in northern Ohio in Lake Erie and in southwestern Ohio (Trautman, 1957; Daniels 1993). Current distributions for this species are now confined to eastern and central Ohio. Ohio is the center of the eastern sand darter's distribution. Densities of the eastern sand darter in Ohio are thought to be currently stable (Grandmaison et al., 2004).

The Ohio Department of Natural Resources (ODNR, 2010) categorizes bluebreast, tippecanoe, and river darters as threatened and the spotted darter as endangered within the state of Ohio. Based on my data these species' current distributions have remained the same relative to historical distributions. Historically the tippecanoe darter occurred in the Walhonding River and the lower Muskingum River of the Muskingum drainage and in the Olentangy River, Big Walnut Creek, Big Darby Creek, and Deer Creek of the Scioto River drainage (Trautman, 1957). Since the early 1980's they have made an impressive expansion of their distribution in the Scioto River drainage where they can now be found in nearly every major tributary to the Scioto River and the main-stem of the Scioto River from Columbus downstream to the Ohio River (ODNR, 2010). Unfortunately populations of tippecanoe darter have been extirpated from the Muskingum River drainage with the exception of a small population in the lower end of the Muskingum River. There are many dams upstream of their location, so the growth of the remaining Muskingum River population is unlikely (ODNR, 2010). Increases in the tippecanoe darter's distribution suggest that it is likely that conservation efforts have worked in some places and that better habitat quality has helped keep populations viable. Bluebreast darters occur in medium to large streams and rivers only in the Ohio River drainage within Ohio. At one time they had become quite rare in the state with only occurring in limited portions of the Muskingum and Scioto River drainages (ODNR, 2010). Fortunately, as a result of improved water quality, the bluebreast darter has made an impressive recovery in Ohio. They now have distributions in every major tributary to the Scioto River from Columbus to the Ohio River. They have also made a similar expansion in the Muskingum River drainage (ODNR, 2010). The data obtained from the microhabitat analysis of Big Darby Creek showed the bluebreast darter as occurring in several riffles sampled. This is a rare darter that is relatively abundant within this protected habitat.

In my study, landscape position included an evaluation of the range of drainage areas and gradients within which each darter species occurred. Common species generally occurred in small to moderate streams as well as large streams throughout the watershed. Common species continue to be found in large numbers where they occur. Rare species are generally confined to larger rivers – i.e., rivers with moderate gradients (between 1 and 10 ft/mi) and relatively large drainage areas (500-1000 mi^2). The data from my study do not reveal why rare species do not occur in small streams. Either small streams are heavily impacted by human modification of the landscape, or rare darters have never occurred in headwater streams.

Streams are hierarchal systems in which climate, geology, and topography at larger scales (i.e. landscape scale) establish the structure for geomorphic processes that create and sustain habitat at smaller scales (i.e. mesohabitat and microhabitat scales) (Allen & Starr, 1982; Frissell et al., 1986; Montgomery, 1999). At the same time, streams are linear systems in which instream stressors at particular locations can have heightened effects that influence properties of the entire system (Fausch et al., 2002). The first requirement for understanding the relative effects of instream stressors is comprehensive monitoring data. The state of Ohio utilizes habitat assessment criteria that are correlated with the biological integrity of a river system.

Methods for monitoring the ecological condition of water reserves have developed a great deal in recent years as several states and federal agencies now regularly collect water quality data, physical habitat data, and biological data using random sampling designs and standardized collection methodologies. The Ohio EPA uses a physical habitat index as a tool for assessing causes of destruction and for assigning aquatic life uses (Ohio EPA, 2010; Rankin 1989). The index of biotic integrity (IBI) along with habitat quantification (QHEI) and water chemistry assist in evaluating a river's health (An et al., 2002). Watersheds are often rated as good, fair, or poor with regard to a single stressor or with regard to an index of biotic integrity (Yuan & Norton, 2004). In my study, the macro-scale approach QHEI was a useful tool for assessing the habitat needs of rare darters. All darter species, except for the johnny darter, showed a positive relationship between QHEI and abundance. The johnny darter had the greatest abundance compared to all other darters and the number of individuals was negatively associated with the QHEI. This unimodal relationship affected the results for other darters because johnny darters occurred frequently in what appeared to be unsuitable habitat for all other species. Therefore, the occurrence of most darters, both common and rare, was positively associated elements of the QHEI even though I restricted the analysis to sites where some species of darter occurred.

Researchers would consider the johnny darter to be a “trash fish”, being able to thrive in areas of fair to poor habitat quality. This species appears to exploit a wide range of habitats and are not sensitive to various habitat variables such as sedimentation. The johnny darter tolerates what the QHEI considers a marginal habitat, a habitat supporting only a few species or individuals due to restrictive environmental conditions. Johnny darters are the most common and widespread of the darters in Ohio according to my study. It is not as sensitive as other species of darters to high turbidity and will tolerate some siltation of its habitat (ODNR, 2010; Trautman, 1957). Johnny darters are among the first fishes to move into new aquatic habitats or to recolonize a stream after a catastrophic event (ODNR, 2010). They seem to tolerate many kinds of water pollution, more so than other darters species (Trautman, 1957).

Darter abundance was positively correlated with the overall QHEI as well as with many of the individual elements of the QHEI that designate “good habitat.” Few sites with darters had low QHEI values. High habitat quality could be due to conservation being heavily implemented throughout Ohio since the fish occur in those regions. The majority of darter species occur together in regions with high QHEI scores. As the number of darter species increases at a site, the higher the QHEI value is at that site. Darter densities, excluding the johnny darter, increased with increasing QHEI scores. In the Lower Olentangy River Watershed, for example, common darters including the greenside, rainbow, and banded darters are considered pollution-intolerant species (Friends of the Lower Olentangy River Watershed Inventory, 2003), which is not to be expected since common darters have widespread distributions. The Lower Olentangy River Watershed is a protected region where common darters occur in dense densities in good habitat.

Darter abundance was not consistently related to channel and riparian score. Although some mesohabitat variables are important for all species, it is not until the microhabitat scale where cover and substrate become more important for each darter species. Unlike my study, several studies have found that riparian depth add protection to streams and fish abundances (Miltner, White, & Yoder, 2003). Conservationists' primary focus of management has been on protecting and increasing these vegetative zones. In the Big Darby Creek watershed, riparian score and percent urban land use in the riparian zone have been associated with changes in Index of Biotic Integrity (Yuan & Norton, 2003). Recall that QHEI is correlated with biological integrity or how a river's health is measured. One species in particular in my study, the rare channel darter, had the greatest difference in riparian score around 2.5 points at sites where it was present compared to where it was absent. In the Lake Ontario basin, the channel darter was found in riffles flowing into deep sand bottomed pools although they were found to be more dependent on reach-scale habitat features than on smaller scale riffle characteristics (Reid, Carl, &

Lean, 2005). This result is consistent with the result of my study. Although not as significant as microhabitat variables to a darter's distribution, mesohabitat does matter when it comes to conservation and protection of areas with rare species.

The microhabitat variables included in the analysis were substrate, cover, riffle, and pool scores. Microhabitat characteristics were the best correlates of an individual species' presence or absence. At this scale water depth and substrate origin and diversity have the capacity to influence a darter's presence (Page, 1983). Stream fish assemblages can be influenced by small-scale habitat variables relating to cover and substrate within pools and riffles (Smith & Kraft, 2005; Lau et al., 2006) and even spatial location or position within a stream network (Smith &Kraft, 2005; D'Ambrosio et al., 2009). This same pattern is consistent with my study where watershed area and microhabitat variables played a major role in where darters reside. Rare species such as the tippecanoe and river darters occurred at sites with higher cover scores at sites compared to sites where common species occurred. A higher cover score means that areas have more cover available as habitat whether it is undercut banks, overhanging vegetation, or rootwads.

The Muskingum and Scioto watersheds are the best preserved watersheds in Ohio. These watersheds are also near the largest in the state. The slightly higher overall QHEI score indicates better habitat or better management in the Scioto River Basin compared to the Muskingum River Basin. A number of riparian corridor protection efforts are ongoing in Ohio in which the ODNR Division of Wildlife works in several different collaborative partnerships. Restoration efforts currently underway focus on rivers including the Kokosing River and Big and Little Darby Creeks, part of the Scioto River basin. The Scioto River flows through Columbus, Ohio, where human activity has altered the majority of the river basin. Channelization and the removal of riparian vegetation, as well as agricultural and urbanization influences, have resulted in damaged water and habitat quality of the Scioto River basin. The Muskingum River's original riparian vegetation consisting of mainly forest has been replaced by crop land. In these watersheds, agricultural practices and urbanization continue to impact the river systems by causing changes in temperature and flow rates (Cormier et al., 2000).

High conservation efforts are being employed in Big Darby Creek, especially within its metro parks. This river supports rare darters that are occurring in certain habitat types. The overall biological condition of the mainstem of the Big Darby Creek watershed has improved since the early 1980s (Schubauer-Berigan et al., 2000); darter abundance also had increased over the time periods that were observed (Schubauer-Berigan et al., 2000). I found that rare darters had a patchy distribution in Big Darby Creek along with different habitat needs such as substrate use. The spotted and tippecanoe darters are distributed in the mid to lower regions of the Big Darby mainstem while the bluebreast darter is distributed throughout the study region. I found only one or two rare darter individuals after seining at a site, while several individuals of common species occurred at all sites.

The QHEI can be a useful tool for determining habitat variables important for conserving fish species, including darters. Darter abundance was positively associated with QHEI in my study suggesting that the habitat index is consistent with darter needs. An increase in agriculture and industrialization in Ohio impacts these rivers, which in turn impact species abundance and presence. By continuing to protect areas where these species dwell and increasing the amount of area that is protected, Ohio conservationists can help with the success of these species. While the QHEI is a good predictor of species abundance, the QHEI only looks at stream habitat as a whole and not what a fish is directly experiencing in the position of the stream that they are in. For direct microhabitat observation of darters in their habitat, microhabitat or snorkeling studies can be used see how darters use stream habitat (i.e. position in relationship to substrate, substrate size, direct measure of stream flow). Monitoring of known populations is necessary to determine the status of darters, which the Ohio EPA continues to do every year. Studies should focus on spawning, developmental processes, and behavior. Such information will allow conservationists to initiate successful protection and recovery efforts, to sustain the long-term viability of these species in Ohio and throughout their range. Conservationists can manage for good habitat while focusing on the fact that different species have specific habitat needs whether it is substrate size or water depth. Areas currently being protected should not only continue to be protected, but these areas should be extended.

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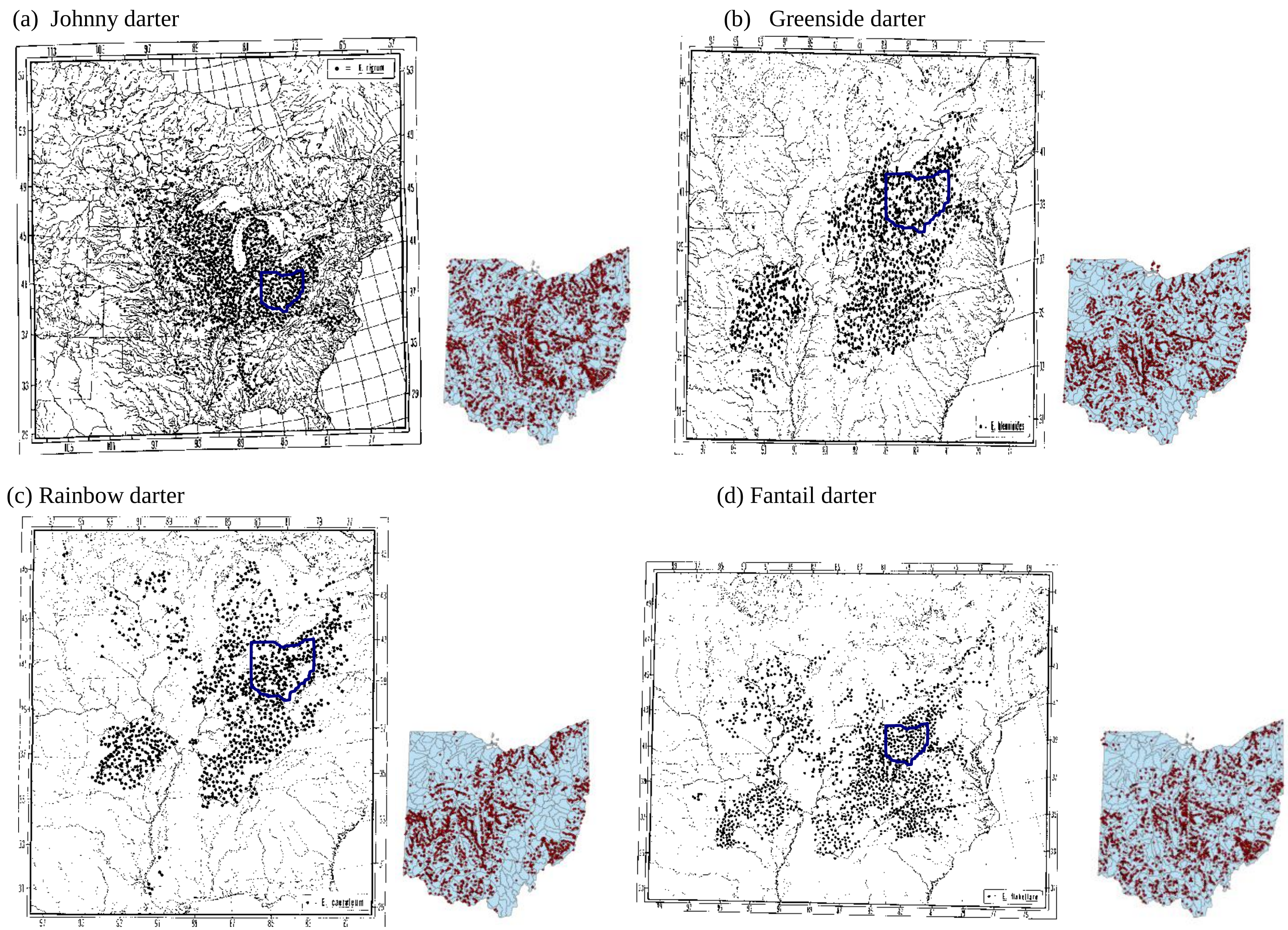
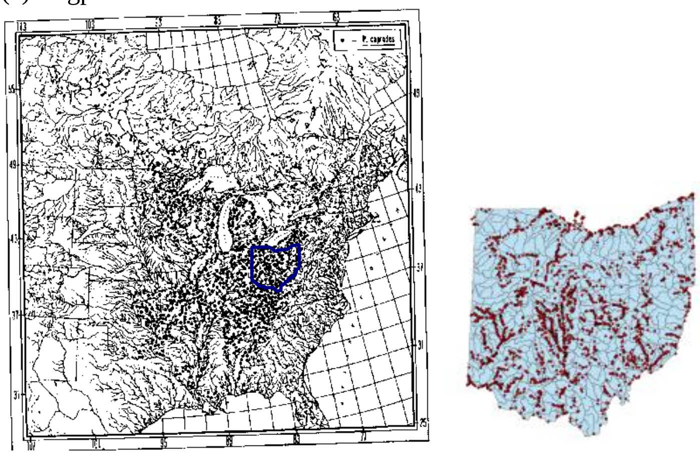
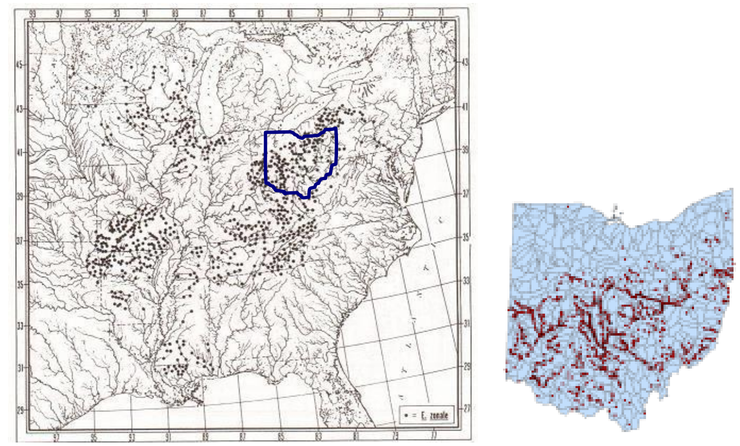


Figure 1. Distribution of nineteen darter species in the Eastern United States, Canada, and in Ohio arranged in order of decreasing abundance within Ohio. The geographic maps are reproduced from Page (1983) with Ohio outlined. The Ohio maps were created in GIS using the Ohio EPA data. (a) Johnny darter, (b) Greenside darter, (c) Rainbow darter, and (d) Fantail darter.

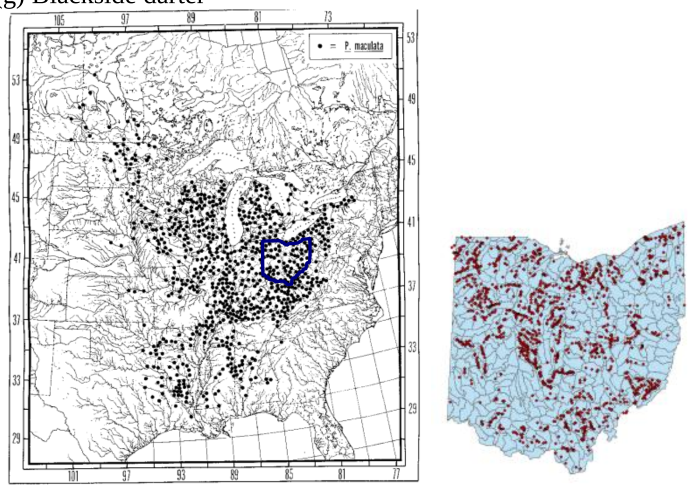
(e) Logperch darter



(f) Banded darter



(g) Blackside darter



(h) Orangethroat darter

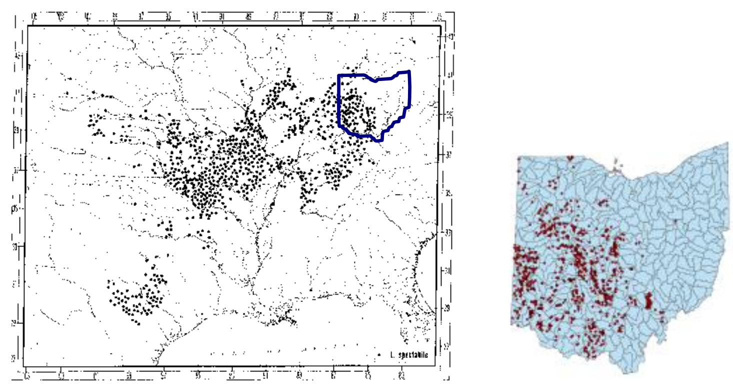
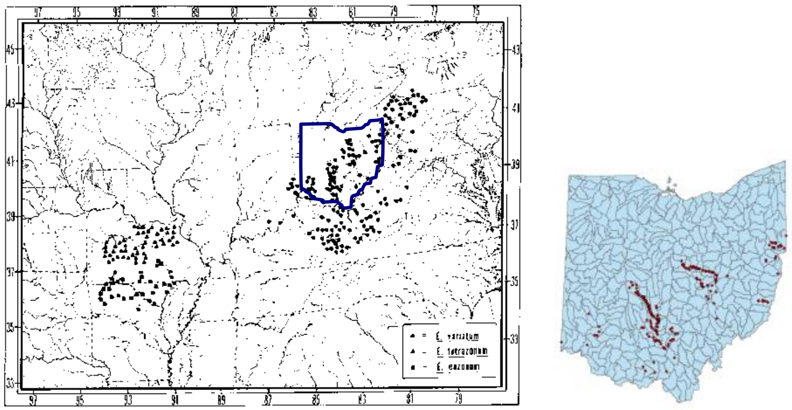
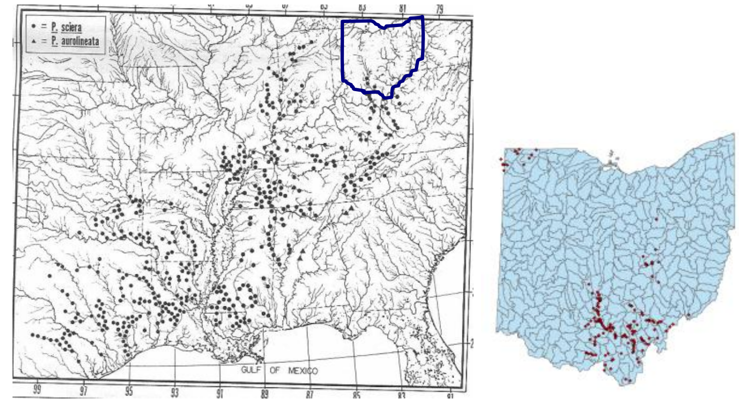


Figure 1. (e) Logperch darter, (f) Banded darter, (g) Blackside darter, and (h) Orangethroat darter.

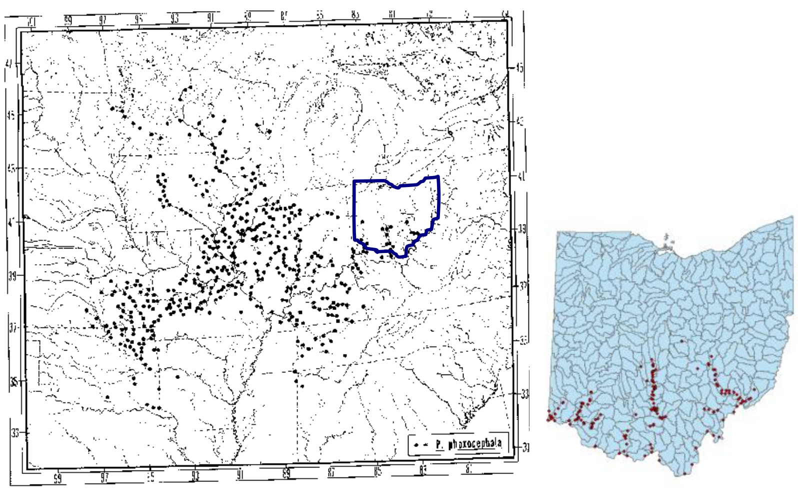
(i) Variegate darter



(j) Dusky darter



(k) Slenderhead darter



(l) Bluebreast darter

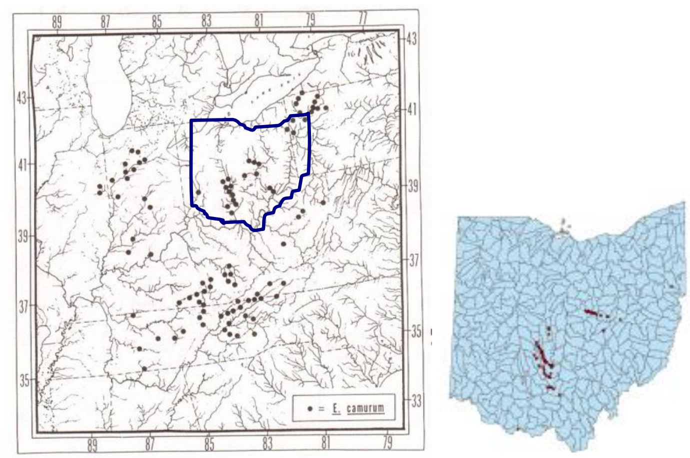
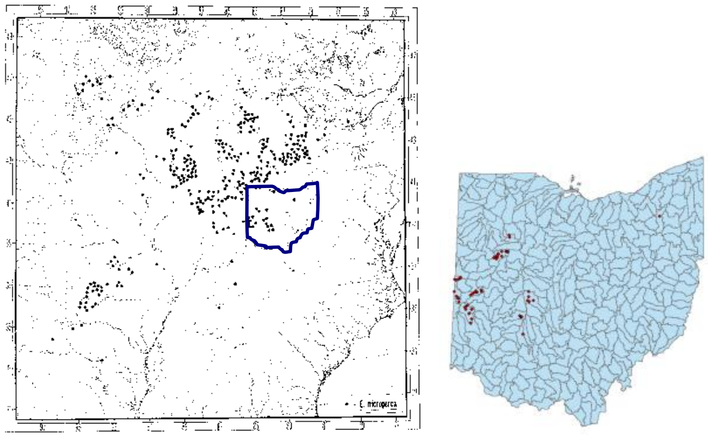
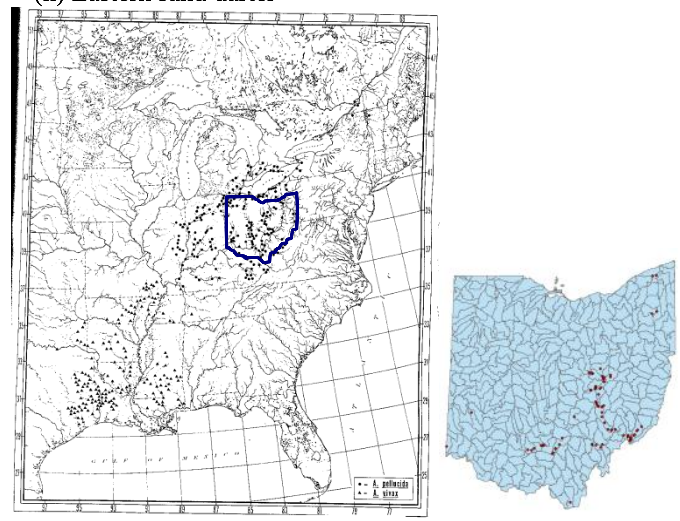


Figure 1. (i) Variegate darter, (j) Dusky darter, (k) Slenderhead darter, and (l) Bluebreast darter.

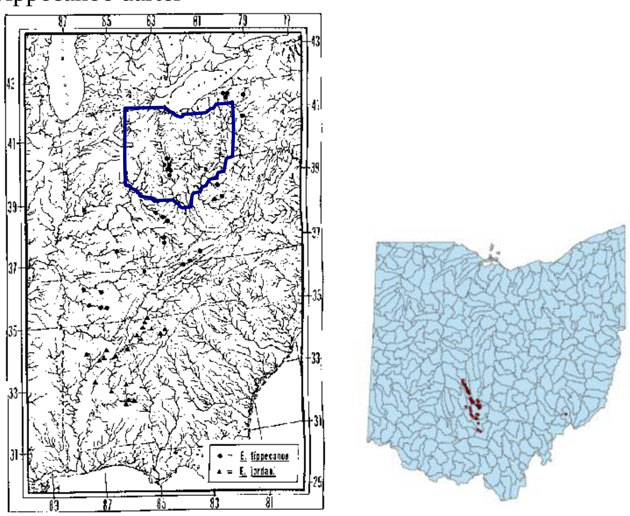
(m) Least darter



(n) Eastern sand darter



(o) Tippecanoe darter



(p) Channel darter

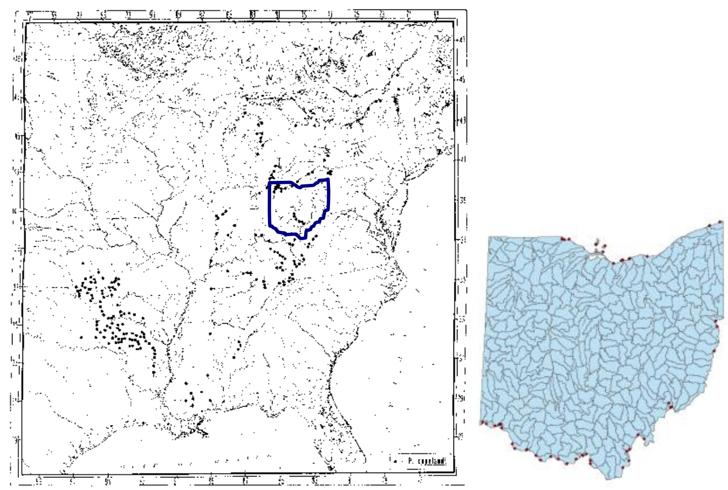
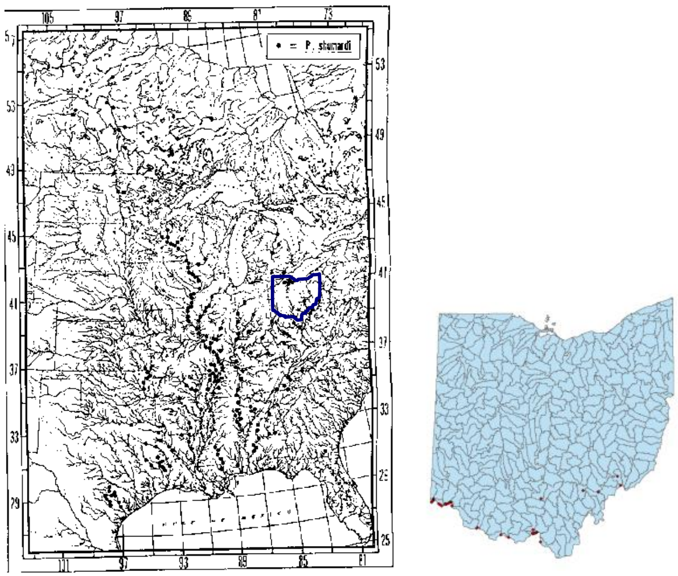
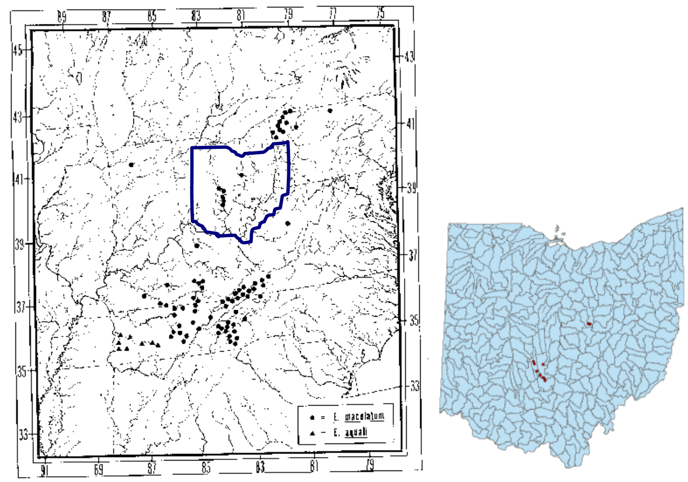


Figure 1. (m) Least darer, (n) Eastern sand darter, (o) Tippecanoe darter, and (p) Channel darter.

(q) River darter



(r) Spotted darter



(s) Iowa darter

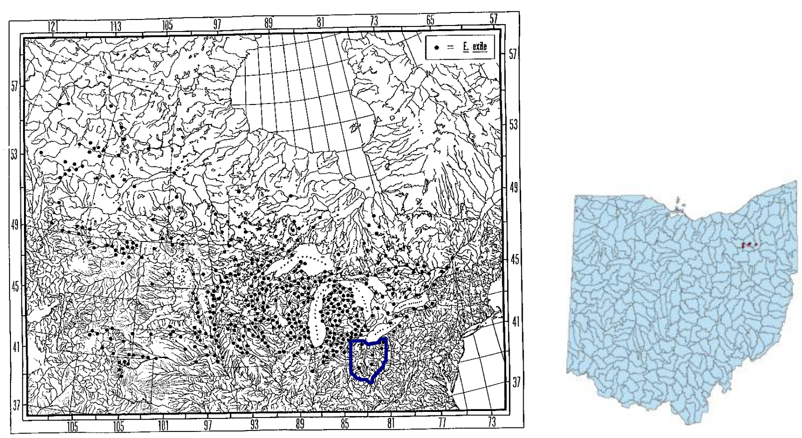
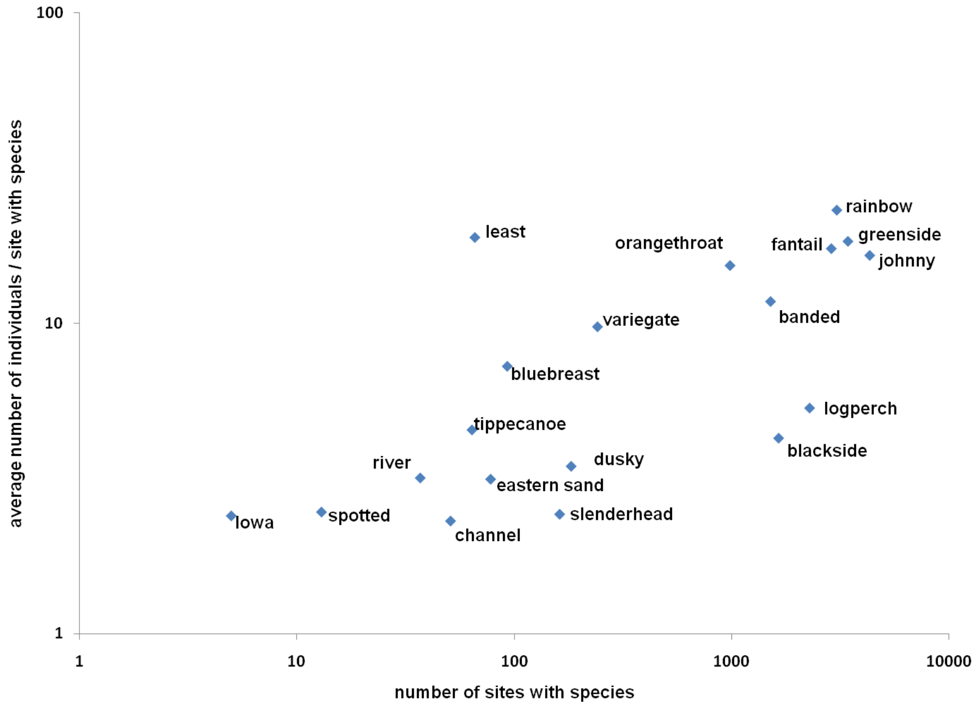


Figure 1. (q) River darter, (r) Spotted darter, and (s) Iowa darter.

a)



b)

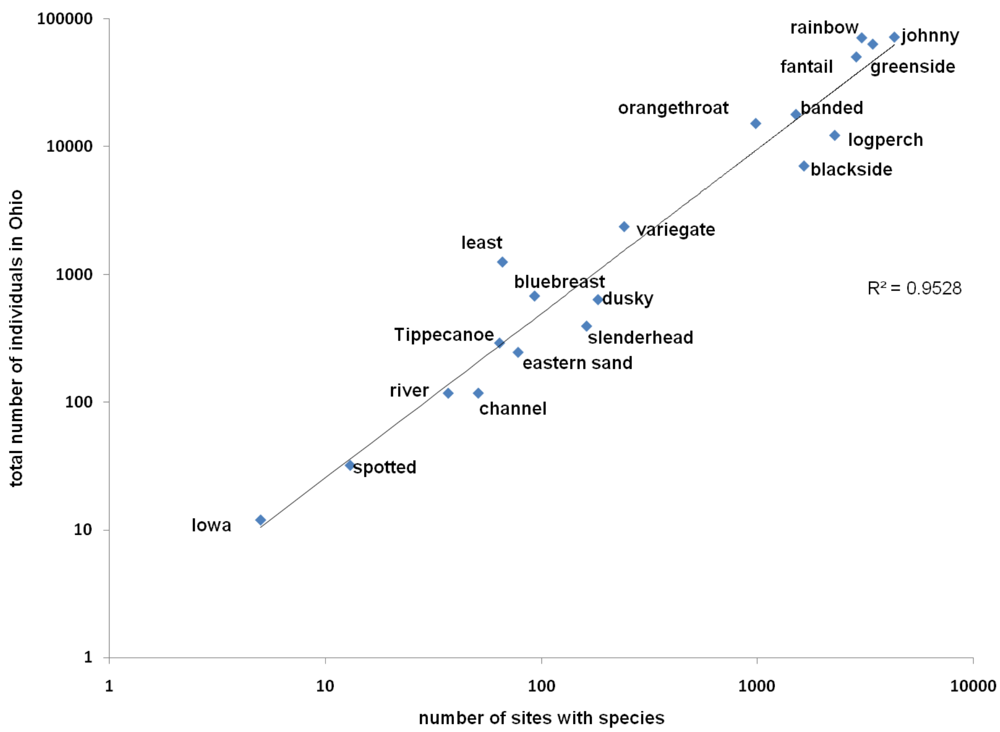


Figure 2. Scatterplots showing the relationship between the number of sites where a particular species was present and (a) the average number of individuals per site. Only sites where the species was were included in the average (i.e. values of 0 were excluded). and (b) total number of individuals in Ohio.

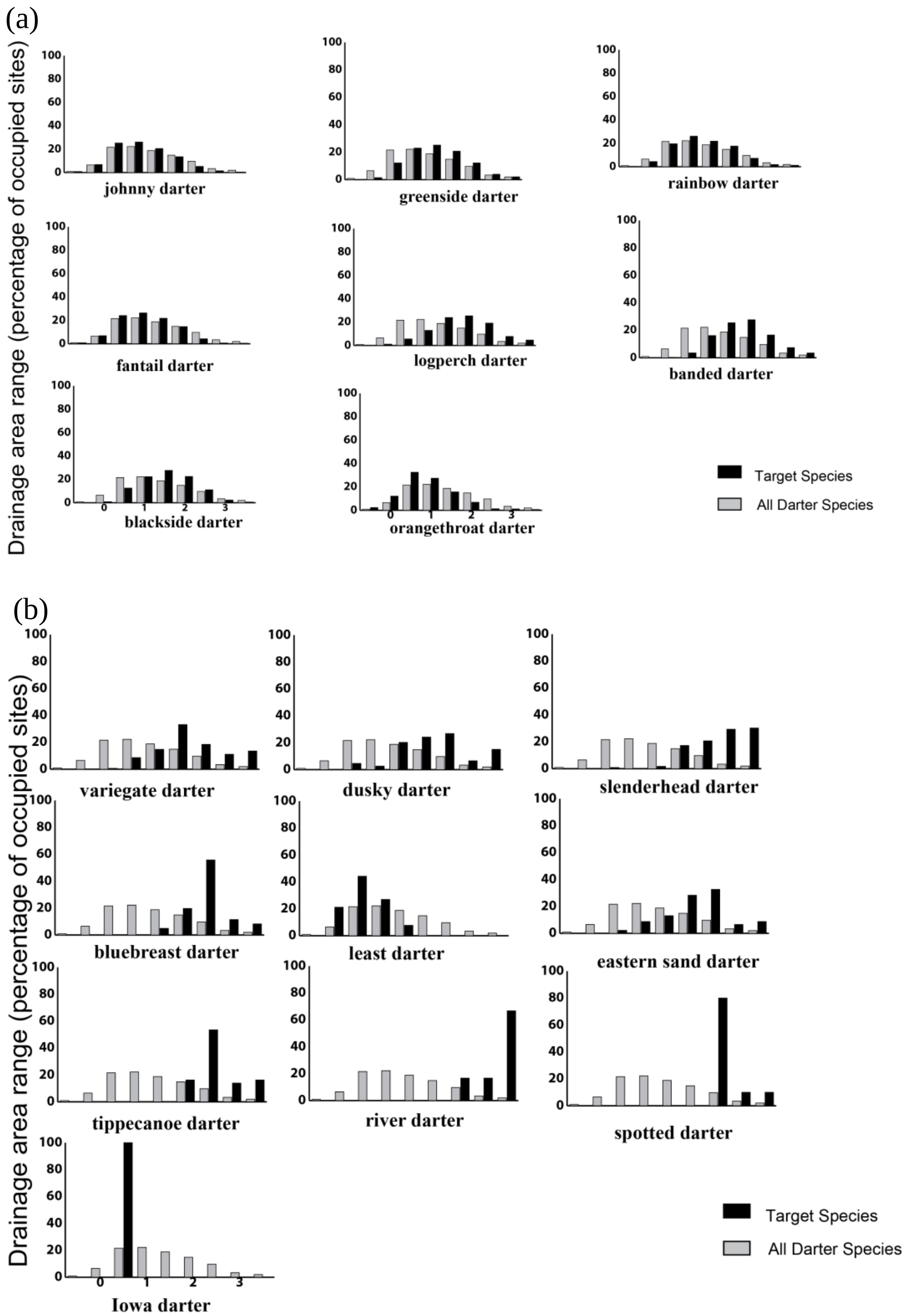
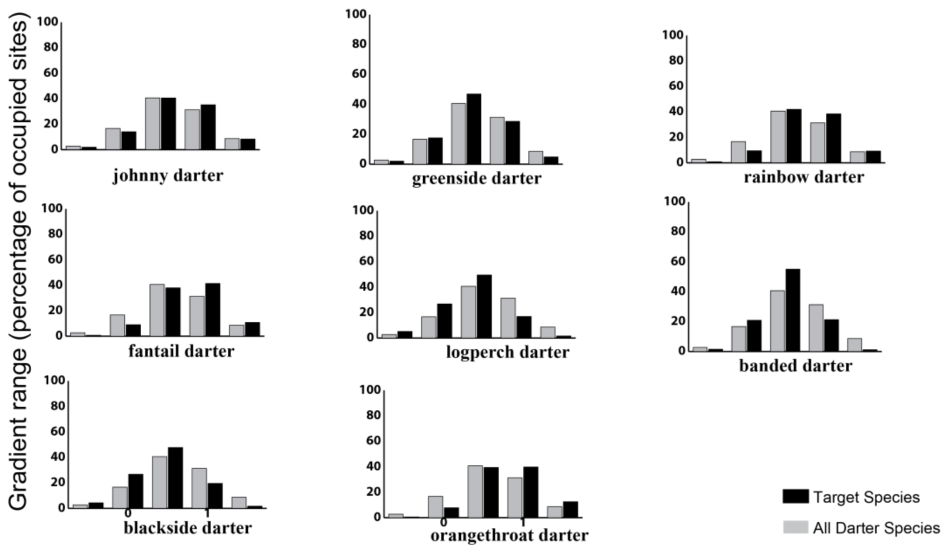


Figure 3. Darter abundance as a function of drainage area (square miles) for each of Ohio's nineteen darter species. Drainage area is log transformed and grouped into bins on the x-axis with the median value reported. The y-axis is the percentage of sites where a species is found. Figures are ranked by species in order of decreasing darter abundance. The gray bars show the relative distribution with respect to drainage area of all darter species in Ohio combined. The black bars represent the relative distribution with respect to drainage area for each species. (a) Most common species occur in a wide range of drainage areas and (b) many rare species are restricted to larger drainage areas.

(a)



(b)

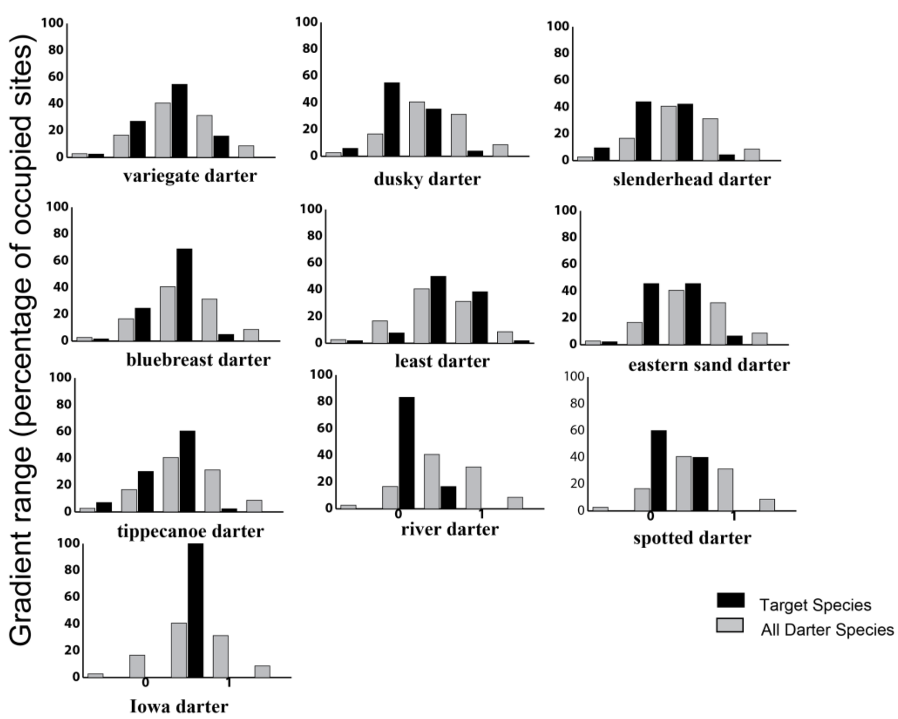


Figure 4. Darter abundance as a function of gradient (feet/mile) for each of Ohio's nineteen darter species. Gradient is log transformed and grouped into bins on the x-axis with the median value reported. The y-axis is the percentage of sites where a species is found. Figures are ranked by species in order of decreasing darter abundance. The gray bars show the relative distribution with respect to drainage area of all darter species in Ohio combined. The black bars represent the relative distribution with respect to drainage area for each species. (a) Each Common species occurs across the spectrum of gradients and (b) rare species do not occur in very high gradient streams.

Figure 5. The Scioto River and Muskingum River Basins are the two largest basins in Ohio with several darter species, 17 and 16 respectively. These basins were chosen to further explore the relationship with habitat quality and darter abundance.

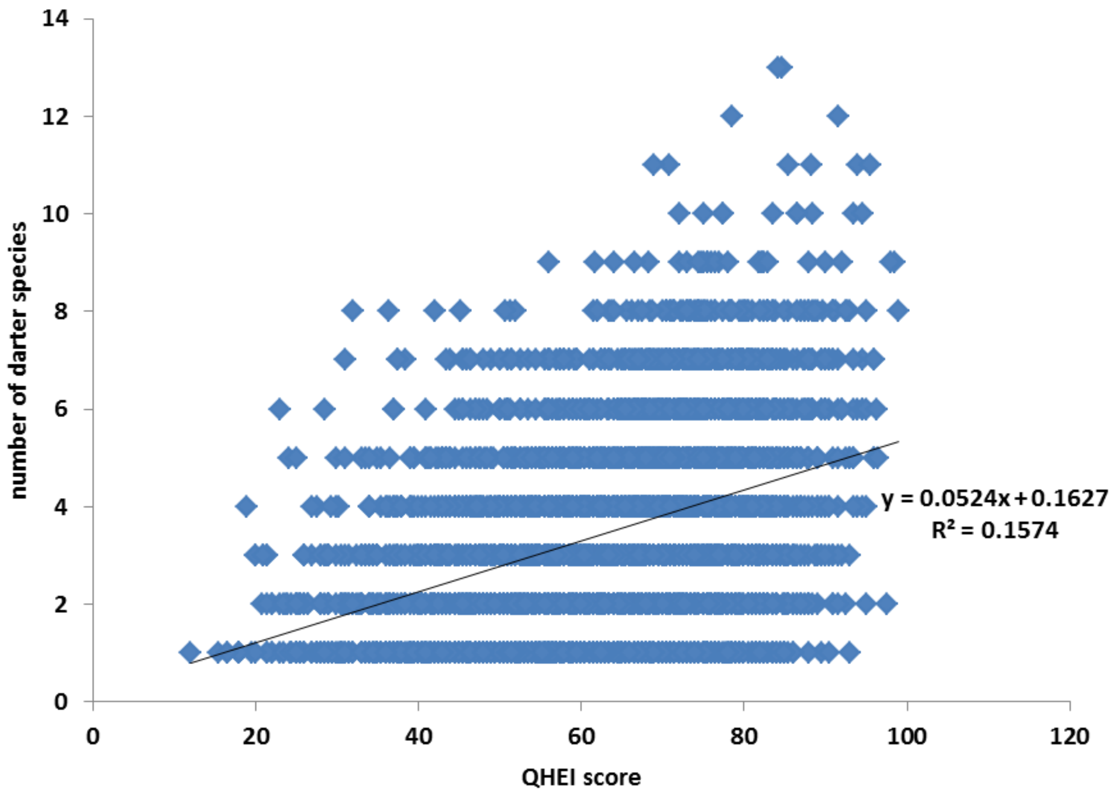
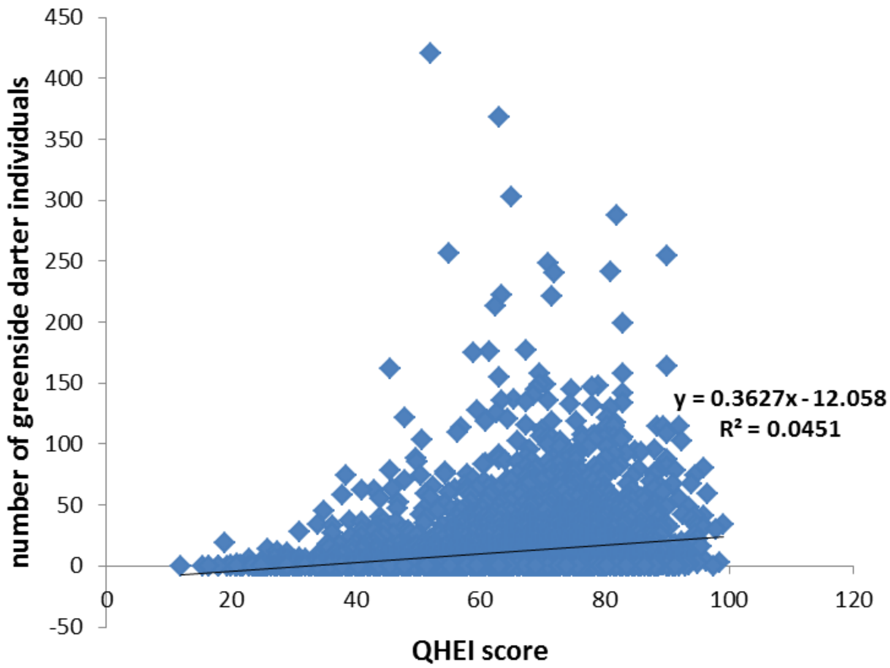


Figure 6. The relationship between the number of species present at a site and the QHEI. Species richness (>8 species) only occurs in areas of relatively high habitat quality (QHEI score >60).

(a)



(b)

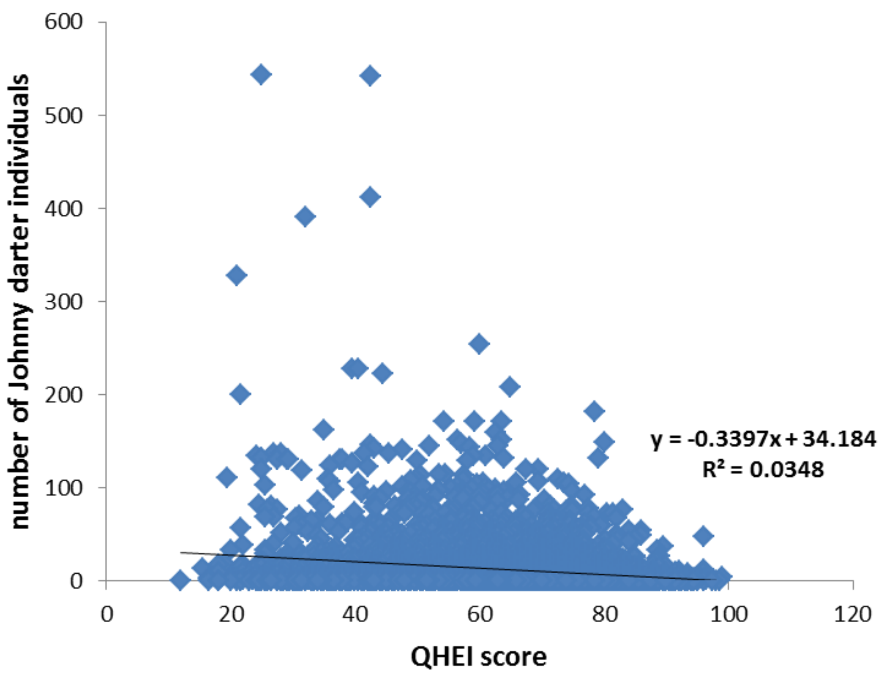


Figure 7. The relationship between the number of darter individuals for two common darters compared to the QHEI score at sites where they are found. a) The greenside darter shows a positive relationship with habitat quality while b) the johnny darter occurs in high densities across the spectrum of QHEI scores and is most abundant at low QHEI scores.

(a) Common (b) Rare

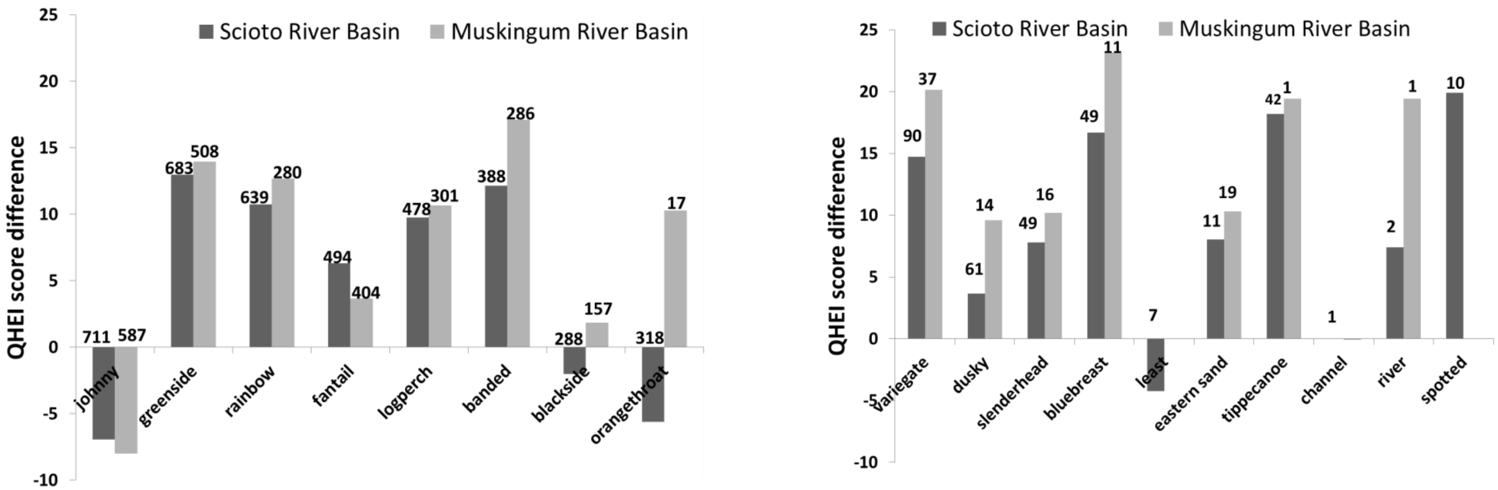


Figure 8. Difference in QHEI habitat scores at sites (presence-absence) for each darter species. Dark gray bars are for the Scioto River Basin and the light gray bars are for Muskingum River Basin. The number of sites at which a species is present is noted at the top of each bar. There are 948 sites with darters in the Scioto River Basin and 750 sites in the Muskingum River Basin. A positive score means that the rare darter occurs in areas with higher scores than at sites where it is not found. Scores were weighted according to the number of individuals found at a site (number of individuals at a site/total number of individuals in the basin). Species are arranged on the x-axis in order of decreasing abundance within the state of Ohio. QHEI score maximum of 100.

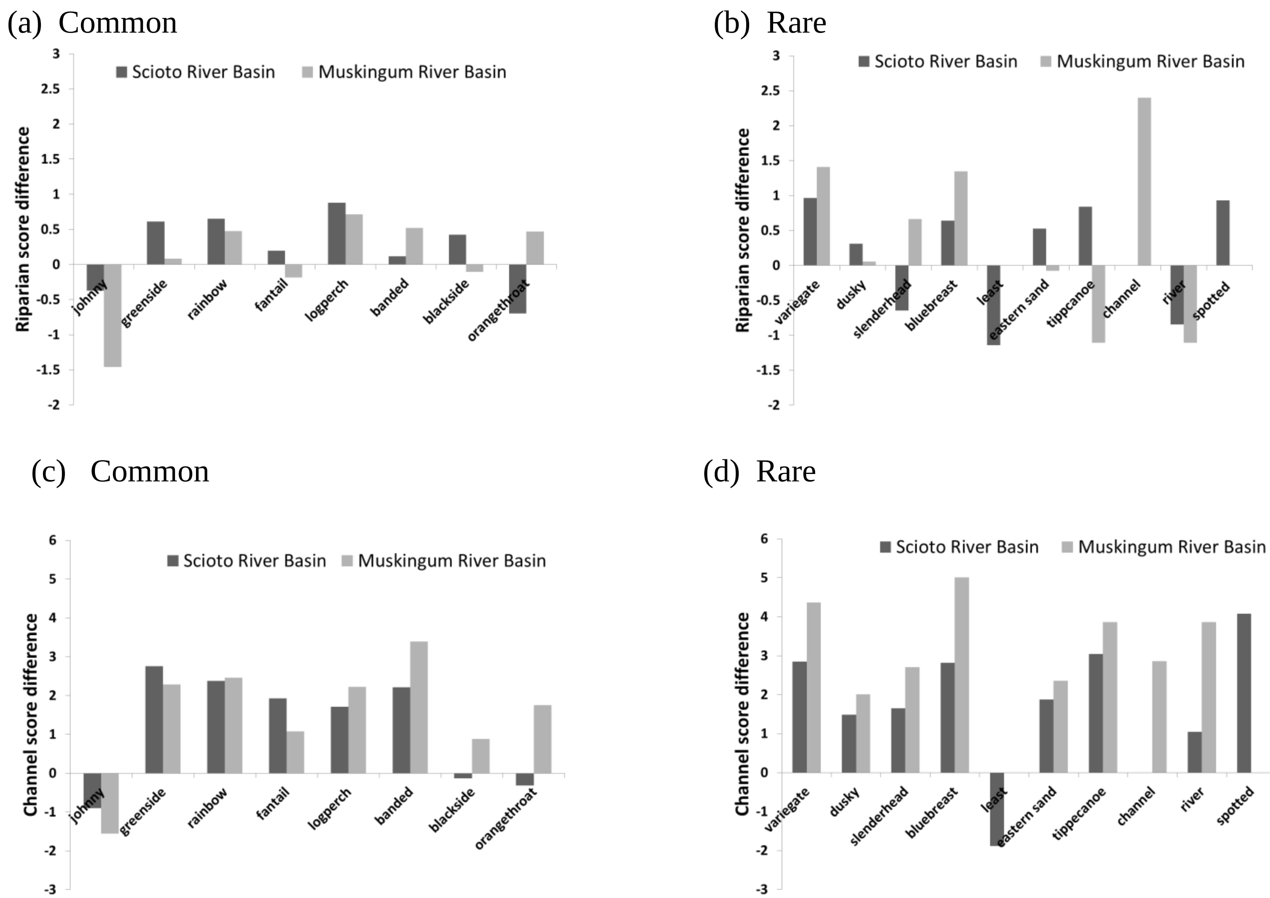


Figure 9. Difference in mesoscale habitat scores at sites (presence-absence) for common and rare darter species. Dark gray bars are for the Scioto River Basin and the light gray bars are for Muskingum River Basin. Scores were weighted according to the number of individuals found at a site (number of individuals at a site/total number of individuals in the basin). Species are arranged on the x-axis in order of decreasing abundance within the state of Ohio. Riparian score maximum of 10. Channel score maximum of 20.

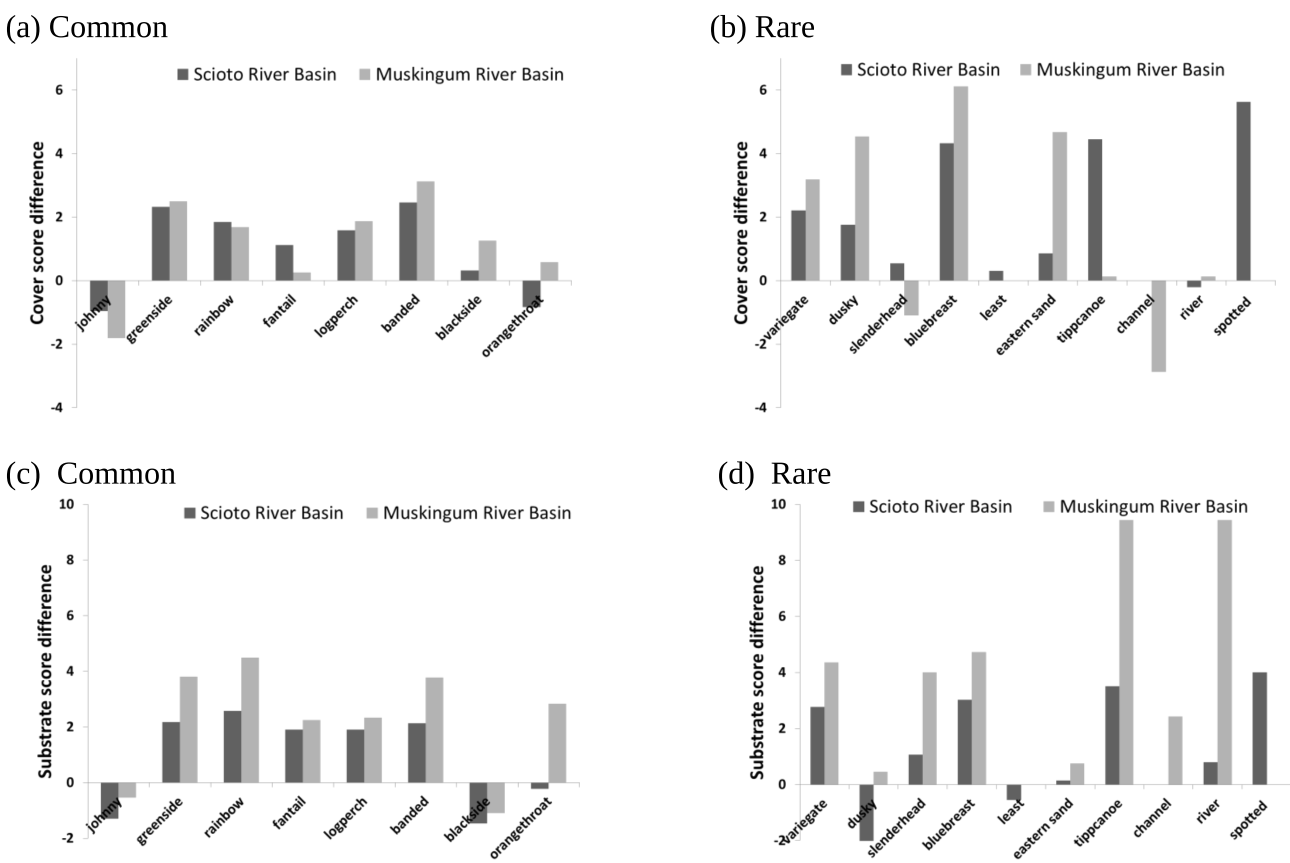
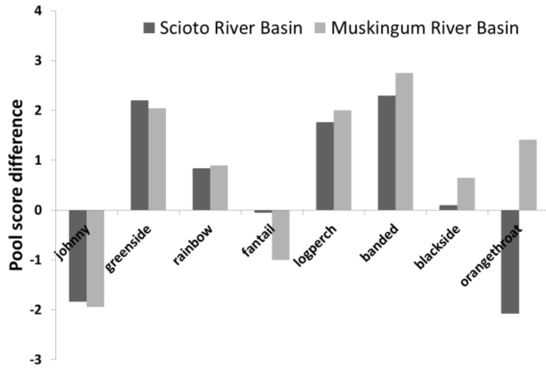
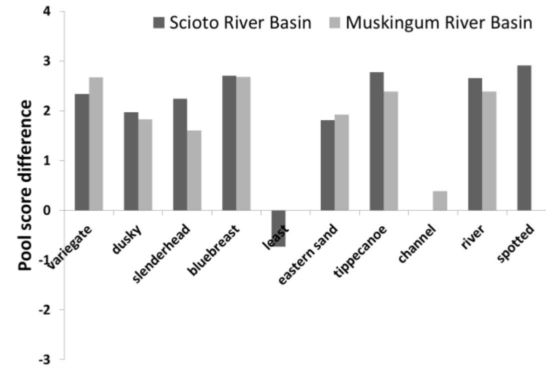


Figure 10. Continues to page 48.

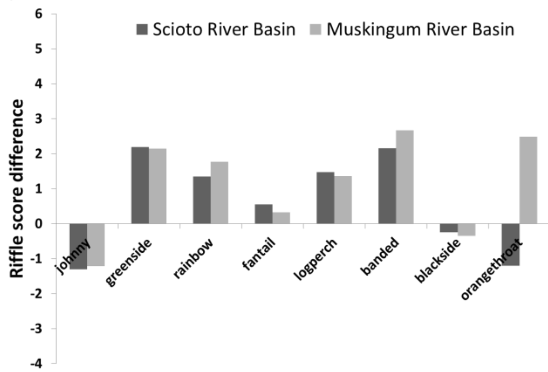
(e) Common



(f) Rare



(g) Common



(h) Rare

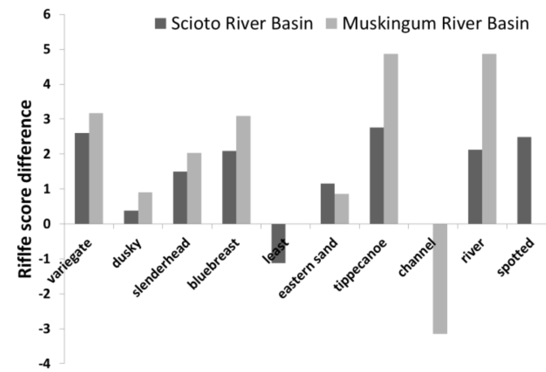
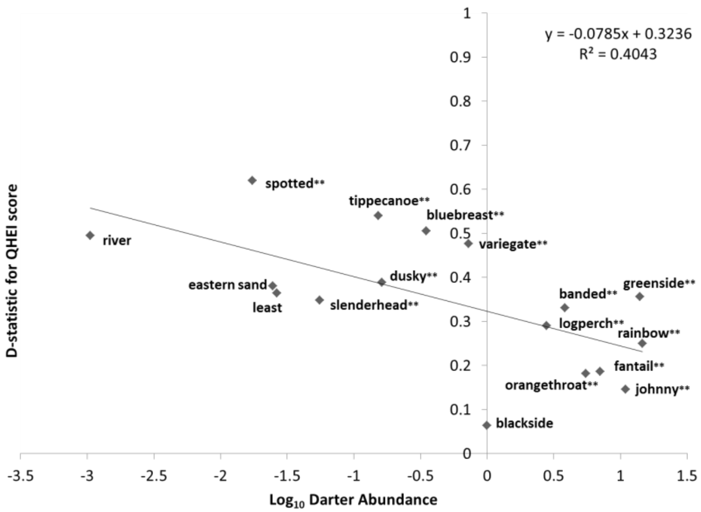


Figure 10. Difference in microscale habitat scores (cover, substrate, pool, and riffle scores) at sites (presence-absence) for common and rare darter species. Dark gray bars are for the Scioto River Basin and the light gray bars are for Muskingum River Basin. Scores are weighted according to the number of individuals found at a site (number of individuals at a site/total number of individuals in the basin). Species are arranged on the x-axis in order of decreasing abundance within the state of Ohio. Cover score maximum of 20 points, substrate score maximum of 20 points, pool score maximum of 12 points, and riffle maximum of 8 points.

(a) Difference in QHEI for Scioto River Basin



(b) Difference in QHEI for Muskingum River Basin

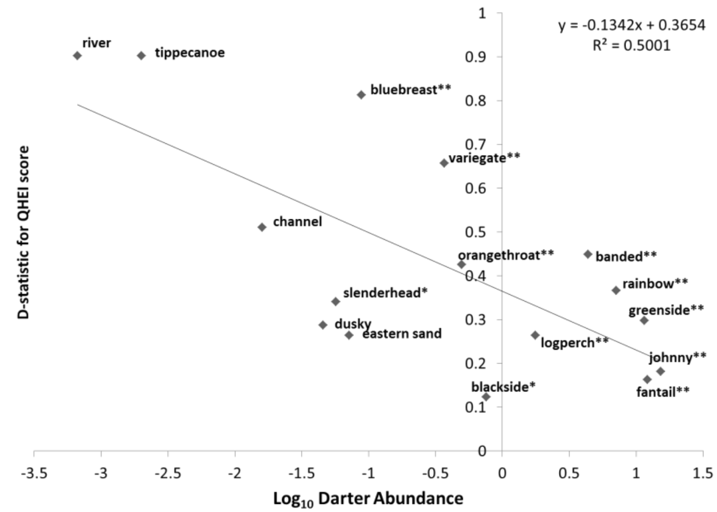
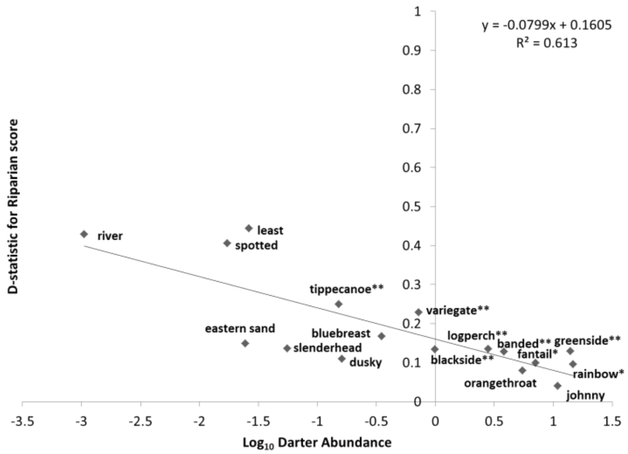
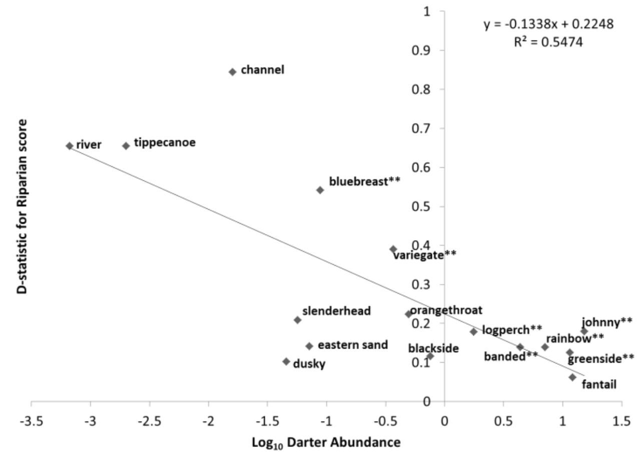


Figure 11. Overall difference in QHEI score examined for Scioto River Basin and Muskingum River Basin against darter abundances with resulting KS test D-statistics (*indicates $p<0.05$, **indicates $p<0.01$ significant difference between QHEI at sites present versus absent).

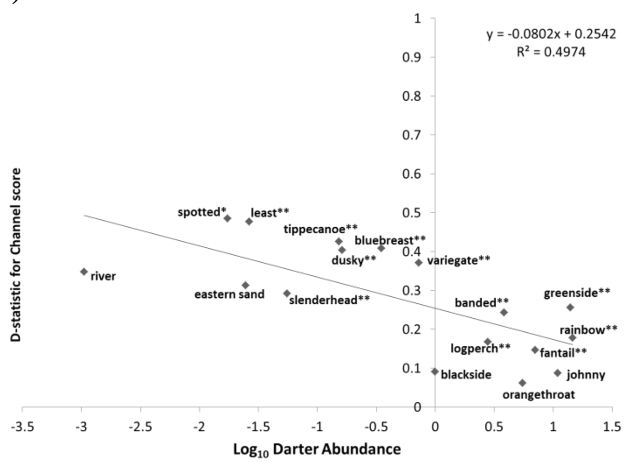
(a) Difference in Riparian for Scioto River Basin



(b) Difference in Riparian for Muskingum River Basin



(c) Difference in Channel for Scioto River Basin



(d) Difference in Channel for Muskingum River Basin

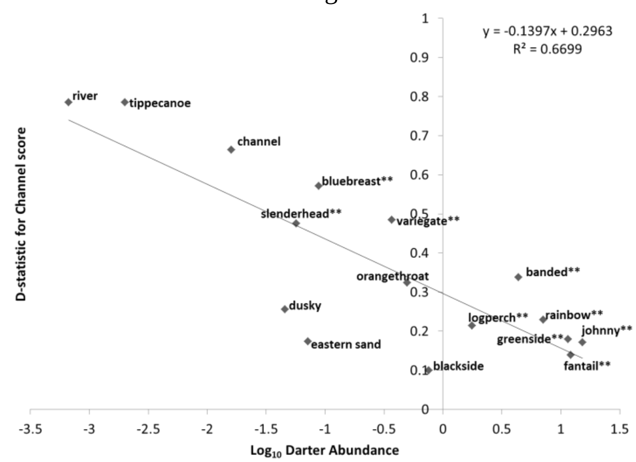
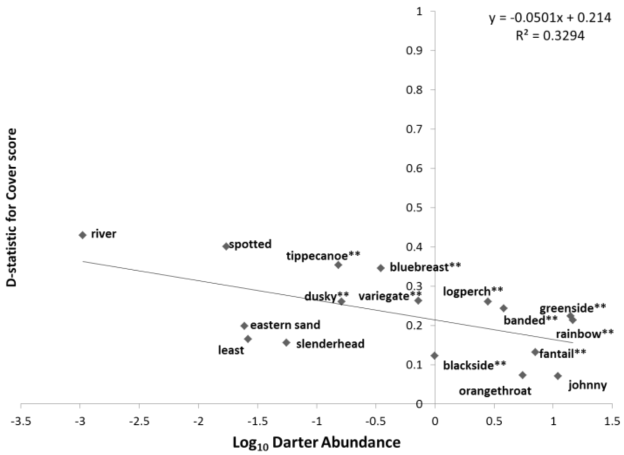
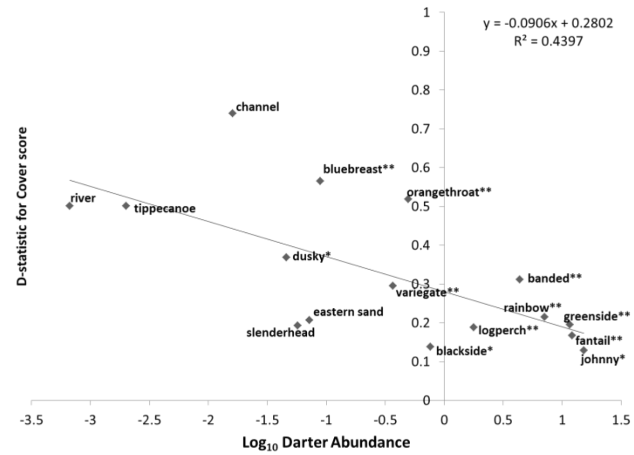


Figure 12. Difference in mesoscale habitat elements examined for Scioto River Basin and Muskingum River Basin against darter abundances with resulting KS test D-statistics (*indicates p<0.05, **indicates p<0.01 significant difference between QHEI at sites present versus absent).

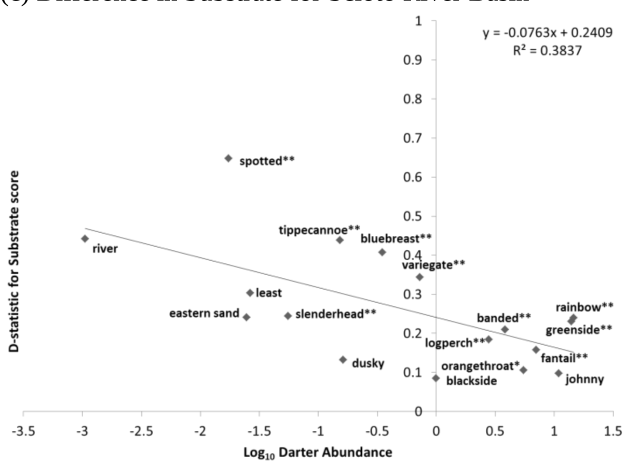
(a) Difference in Cover for Scioto River Basin



(b) Difference in Cover for Muskingum River Basin



(c) Difference in Substrate for Scioto River Basin



(d) Difference in Substrate for Muskingum River Basin

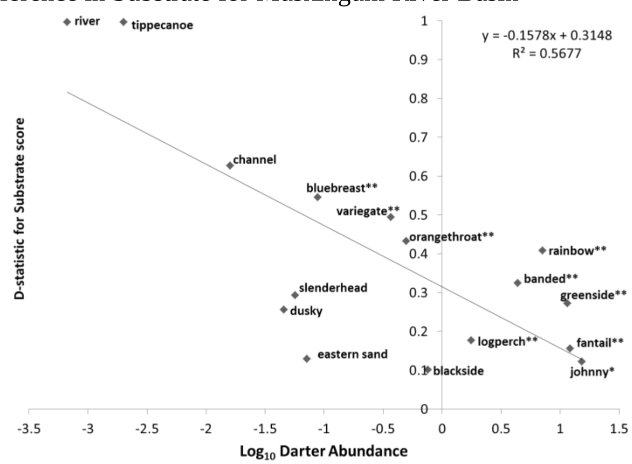


Figure 13 continues to page 52.

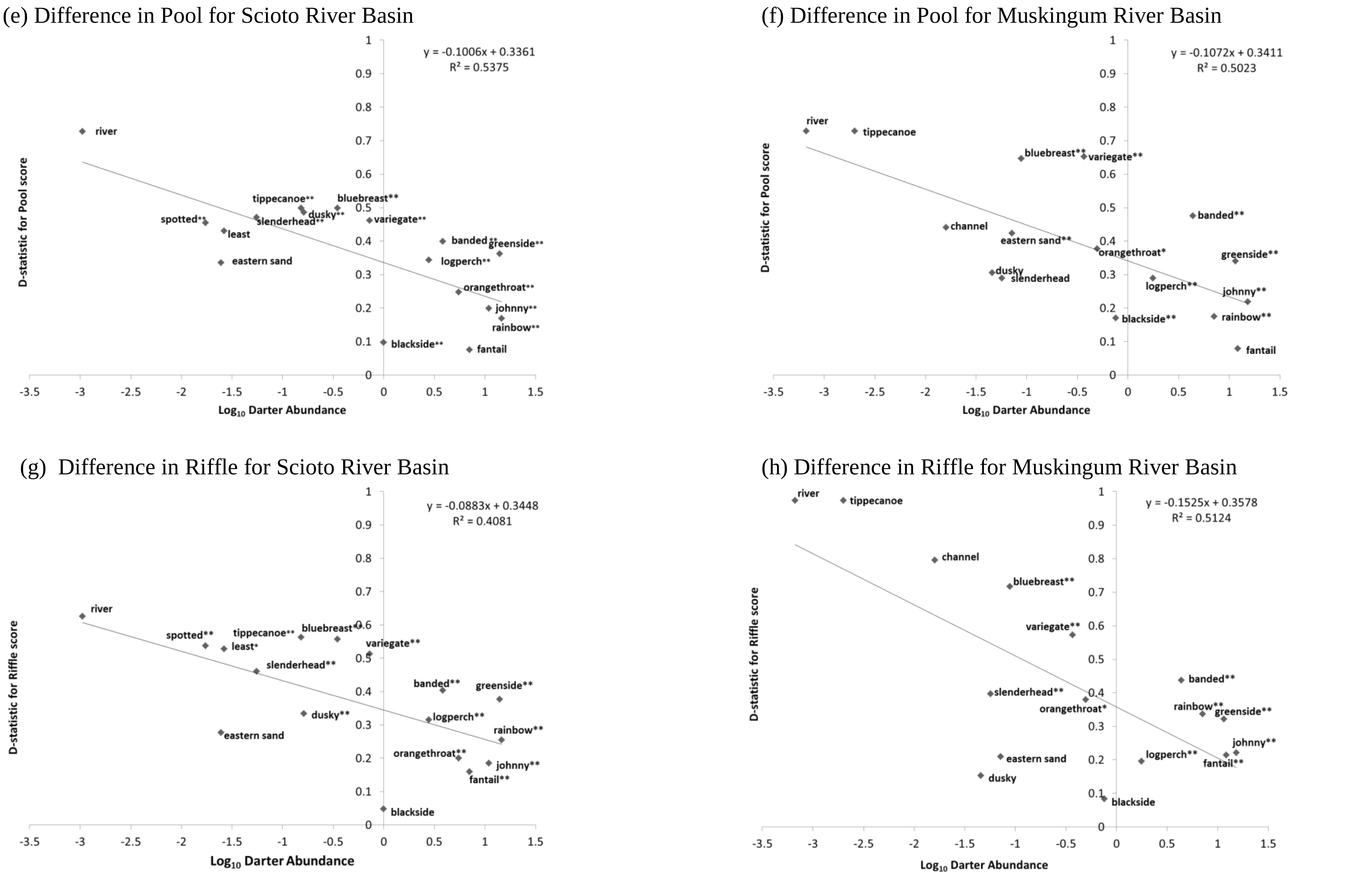
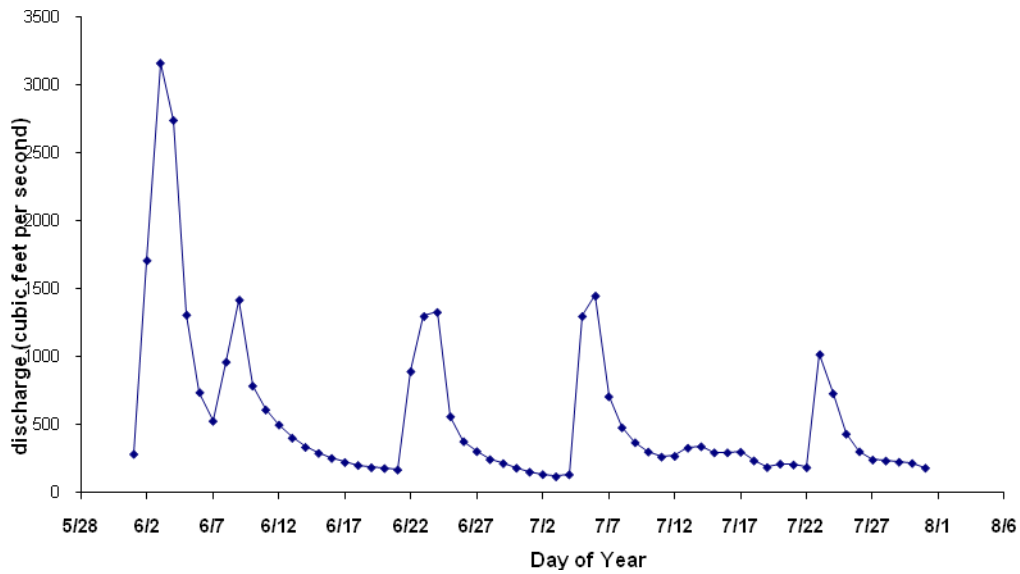


Figure 13. Difference in microhabitat elements examined for Scioto River Basin and Muskingum River Basin against darter abundances with resulting KS test D-statistics (*indicates p<0.05, **indicates p<0.01 significant difference between QHEI at sites present versus absent).

(a)



(b)

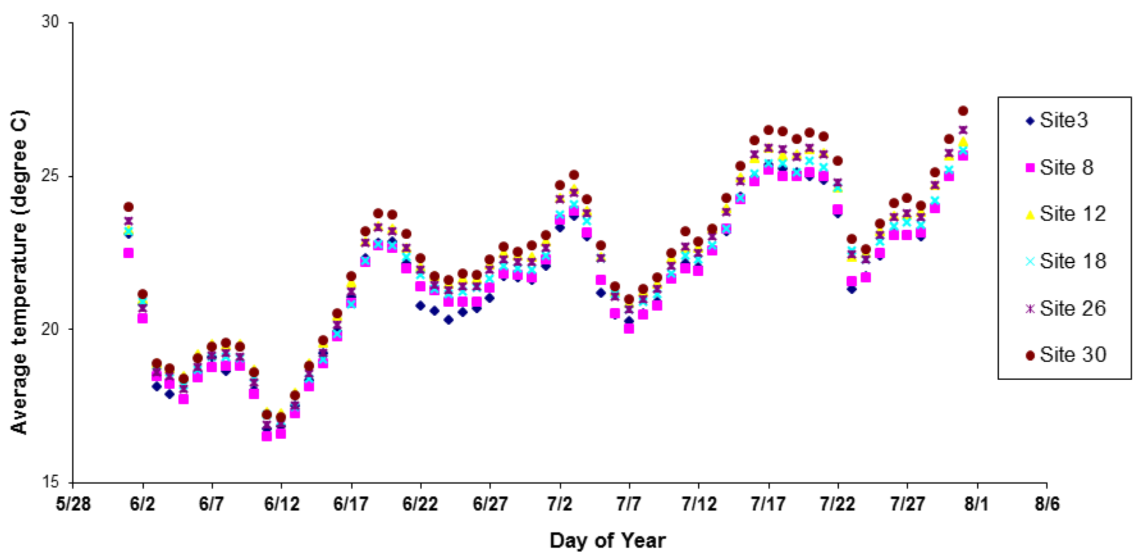


Figure 14. (a) Daily discharge (cubic feet/second) from end of May to beginning of August 2006 and (b) average daily temperatures for Big Darby Creek from June1-July31 2006. Discharge data obtained from Ohio USGS. Note: Site 3 is the farthest upstream site. There is an inverse correlation between temperature and discharge. Temperature also increases from upstream to downstream.

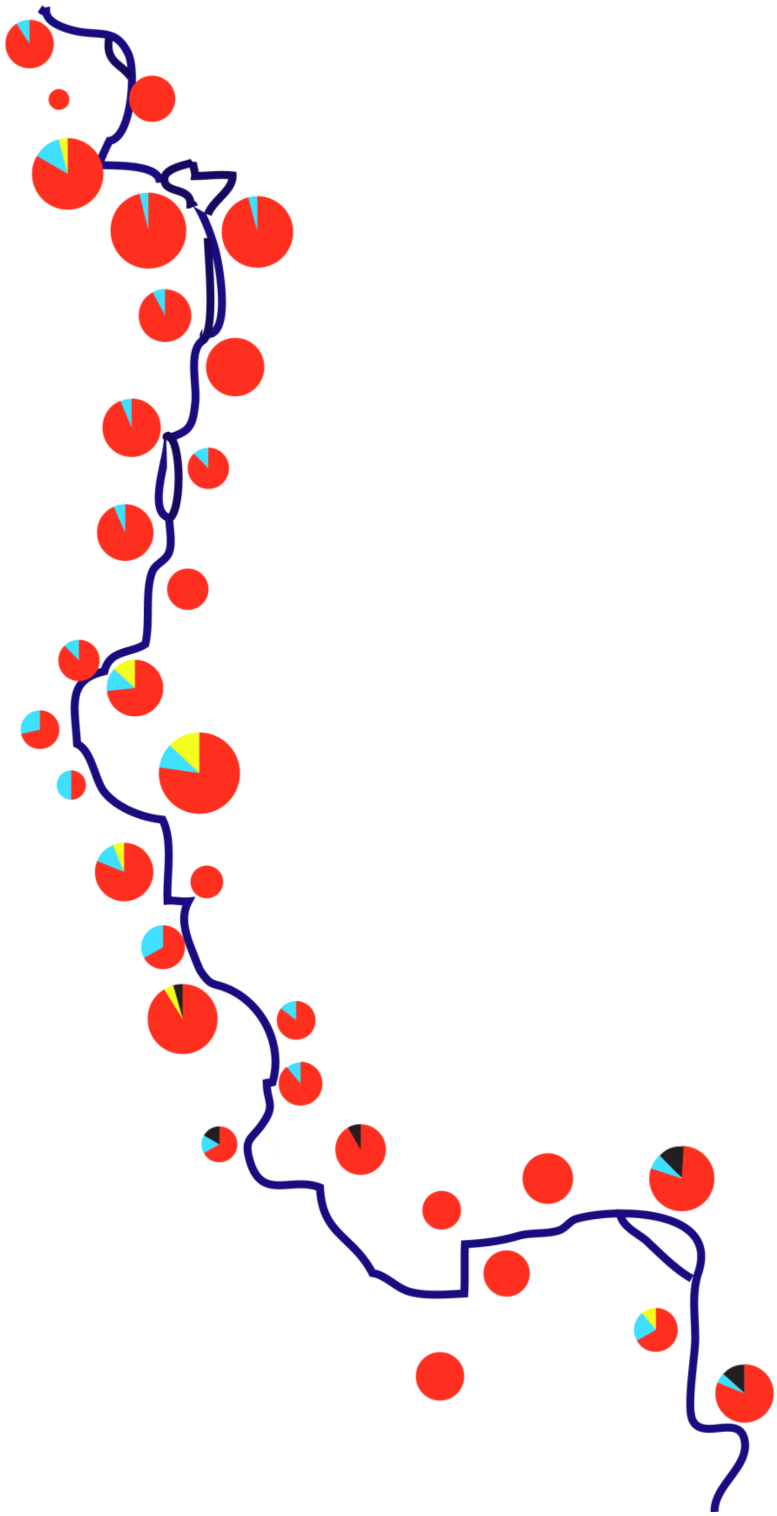


Figure 15. Distribution and abundance of darter species in 13km of Big Darby Creek within Batelle-Darby Creek Metopark. Red represents all common darters. For the rare darters, yellow represents tippcanoe darters, blue represents bluebreast darters, and black represents spotted darters. The pie charts vary by size according the number of darters present.

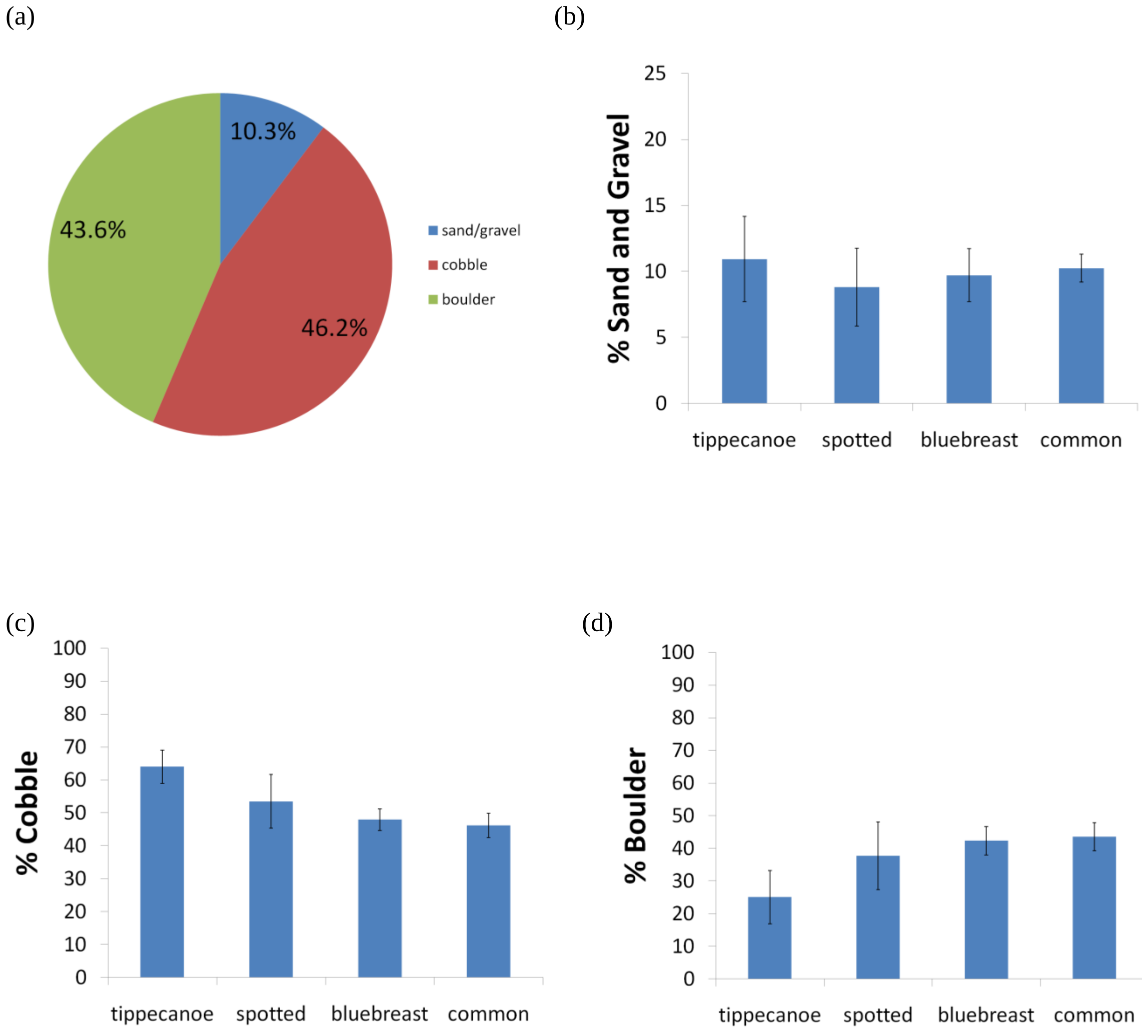


Figure 16. Substrate composition at sites where a darter species occurred. The x-axis is the percent of a site surface covered by a given substrate. (a) average proportion of substrate type found at study sites, (b) % sand/gravel, (c) % cobble, and (d) % boulder composition for rare and common darters in Big Darby Creek.

Table 1. Habitat use of darters modified from Trautman (1957) and Kuehne & Barbour (1983).

Common name	**Scientific name**	**Substrate preference**	**Flow preference**	**River size**
Johnny darter	*Etheostoma nigrum nigrum*	sand/silt bottom	sluggish areas	streams of various size, gradient, substrate, and clarity
Banded darter	*Etheostoma zonale zonale*	stones, boulders, bedrocks	shallow and sluggish	rivers and large creeks of moderate gradient
Rainbow darter	*Etheostoma caeruleum*	sand, gravel, boulders	larger, faster riffles	creeks and small rivers of moderate gradient
Orangethroat darter	*Etheostoma spectabile spectabile*	sand, gravel w/or w/o silt covering	slow to swift riffles	headwater streams
Greenside darter	*Etheostoma blennioides*	gravel, rubble	steady current	all types of riffles, medium-sized to large creeks, small rivers
Fantail darter	*Etheostoma flabellare flabellare*	gravel, flat stone and boulders	shallow and sluggish	streams with 1st-8th order
Variegate darter	*Etheostoma variatum*	clean glacial rubble and boulders	deeper riffles in fall, current rapid	rivers and their large tributaries
Least darter	*Etheostoma microperca*	soft muck bottoms, debris, sand or gravel	sluggish flow	lakes, clean streams, creeks, pools below springs
Iowa darter	*Etheostoma exile*	sand, peat, much, organic debris	not reported	glacial lakes, marshes, and ponds
Spotted darter	*Etheostoma maculatum*	gravel, boulders	rapid current	strong riffles of large streams
Bluebreast darter	*Etheostoma camurum*	many large stones, boulders, some sandy gravel	faster flowing and deeper w/slower current riffles	medium-sized to large rivers
Tippecanoe darter	*Etheostoma Tippecanoe*	gravel and sand	slow, moderate current	heads/tails of riffles, rivers or large creeks
Blackside darter	*Percina maculata*	sand/gravel	sluggish portions of riffles	medium-sized creeks and small to medium-sized rivers
Dusky darter	*Percina sciera sciera*	gravel	low to moderate	medium to large streams
Slenderhead darter	*Percina phoxocephala*	sand, small gravel, rubble, bedorck	strong flow	riffles free of silt; medium –sized creeks to large rivers
Logperch	*Percina evides*	sand or gravel	moderate currents	variety of environments; most common in rivers of moderate size
River darter	*Percina shumardi*	gravel or bedrock	swift currents	waters deeper than 3', riffles or moderate or large-sized streams; deeper lower ends of riffles
Channel darter	*Percnia copelandi*	coarse-sand, fine-gravel or sand	sluggish currents	waters more than 3' deep; rivers and large creeks
Eastern sand darter	*Ammocrypta pellucida*	sand	slow current	moderate- or large-sized streams,; creeks to large rivers

Table 2. Qualitative Habitat Evaluation Index (QHEI) components used by the Ohio EPA to quantify habitat characteristics of streams. Gradient and drainage area are represented by a single score in the QHEI with a maximum score of 10. In this study, the actual values for gradient and drainage area were used. Although there is a maximum score for each QHEI category when reporting the overall QHEI, the sum of the sub-component scores can be more than the maximum score and were used in this study.

QHEI categories		Components of categories	Score (maximum)
Substrate score			20
	Substrate type (0-10, two reported)	boulder/slabs, boulder, cobble, hardpan, muck, silt, gravel, sand, bedrock, detritus, artificial	
	Substrate origin (-2-1)	limestone, tills, wetlands, hardpan, sandstone, lacustrine, shale, coal fines	
	Substrate quality (-2-1)	silt heavy, silt moderate, silt normal, silt free	
	Embeddedness (-2-1)	extensive, moderate, normal, none	
Cover score (Instream cover)			20
	Type (0-3 for each type)	undercut banks, overhanging veg, shallows, rootmats, roots>70cm, rootwads, boulders, oxbows, macrophytes, logs/woody debris	
	Amount (1-11)	extensive, moderate, sparse, nearly absent	
Channel score (Morphology)			20
	Sinuosity (1-4)	high, moderate, low, none	
	Development (1-7)	excellent, good, fair, poor	
	Channelization (1-6)	none, recovered, recovering, recent or no recovery	
	Stability (1-3)	high, moderate, low	
	Modifications/other	snagging, relocation, canopy removal, dredging, impound, islands, leveed, bank shaping, one side channel modifications	
Riparian score (Riparian and bank erosion)			10
	Riparian width (0-4)	wide>50m, moderate 10-50m, narrow 5-10m, very narrow <5m, none	
	Flood plain quality (1-3)	forest/swamp, shrub/old field, residential/park/new field, pasture, tillage, urban/industrial, open pasture/row crop, mining/construction	
	Bank erosion (1-3)	none/little, moderate, heavy/severe	
Pool/Current score (Pool/Glide and Riffle/Run quality)			12
	Maximum depth (0-6)	>1m, 0.7-1m, 0.4-0.7m, 0.2-0.4m, <0.2m	
	Morphology (0-2)	pool width>riffle width, pool width=riffle width, pool width<riffle width	
	Current velocity (-2-1)	eddies, fast, moderate, slow, torrential, interstitial, intermittent, very fast	
Riffle/Run score			8
	Riffle depth (0-2)	best areas>10cm, best areas 5-10cm, best areas <5cm	
	Run depth (1-2)	max>50, max<50	
	Riffle/run substrate (0-2)	stable (I.e., cobble, boulder), moderate stable (I.e., large gravel), unstable (I.e., fine gravel, sand)	
	Riffle/run embeddedness (-1-2)	none, low, moderate, extensive	
Gradient (ft./mi)		gradient at the site, used to check accuracy of gradients taken from topographic maps	
Drainage area (sq. mi)		set drainage area for each segment	

Table 3. Total number of darter species present in each basin from 1972-2004. The Scioto River basin and Muskingham River basin have the greatest number of darter species present. All drainage areas are from Wikipedia.org.

Basin Code	River names	No. Darter Species	Drainage Area (mi^2)
1	Hocking River	12	1197
2	Scioto River	17	6517
3	Grand River	7	705
4	Maumee River	10	6354
5	Sandusky River	7	1420
6	Central Ohio River tributaries	11	------
7	Ashtabula River and Conneaut Creek	4	289
8	Little Beaver Creek	9	510
9	Southeast Ohio River tributaries	8	------
10	Southwest Ohio River tributaries	9	------
11	Little Miami River	11	1755
12	Huron River	6	406
13	Rocky River	6	294
14	Great Miami River	13	3948
15	Chagrin River	6	264
16	Portage River	4	------
17	Muskingum River and Little Hocking River	16	8038
18	Mahoning River	8	1140
19	Cuyahoga River	8	809
20	Black River	6	470
21	Vermillon River	6	268
22	Wabash River and Mississinewa River	3	39,950
23	Mill Creek	3	103
24	Lake Erie	5	22,720
25	Ohio River	13	189,422

Table 4. Relationships between darter abundance and absolute difference in relative cumulative frequency distributions between sites of darter presence and sites of darter absence for QHEI and associated habitat scores for the Scioto and Muskingum River Basins.

Basin Name	**Habitat Characteristic**	**R**	**R^2**	**F**	**p-value**
Scioto River Basin	QHEI	-0.6358	0.4043	10.9	<0.01
	Riparian	-0.7830	0.6131	25.4	<0.01
	Channel	-0.7053	0.4974	15.8	<0.01
	Cover	-0.5739	0.3294	7.9	<0.025
	Substrate	-0.6194	0.3837	10.0	<0.01
	Pool	-0.7331	0.5375	18.6	<0.01
	Riffle	-0.7158	0.5124	16.8	<0.01
Muskingum River Basin	QHEI	-0.7072	.5001	15.0	<0.01
	Riparian	-0.7399	.5474	18.1	<0.01
	Channel	-0.8185	.6699	30.4	<0.01
	Cover	-0.6631	.4397	11.8	<0.01
	Substrate	-0.7535	.5677	19.7	<0.01
	Pool	-0.7087	.5023	15.1	<0.01
	Riffle	-0.7158	.5124	15.8	<0.01